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# MODELING AND SIMULATION OF STANDALONE HYBRID PV- WIND RENEWABLE ENERGY SYSTEM BASE CASE STUDY : IRAQ

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This thesis is submitted in Partial
fulfillment of the requirements for the award of the
Degree of Master Electrical Engineering

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JANUARY 2019

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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Dr. SITI AMELY BINTI JUMAAT

For my Mother and Father for their praise, support and worries for me. For my Brothers and Sister for their unbelievable support on all levels . For my beautiful family for everything.

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# ABSTRACT

Energy is very important for countries growth and economy. The global warning of using fossil fuel to generate electricity increase which plays an important role to increase the demand for renewable energy to generate electricity. Renewable energy is the energy that collected from renewable sources like Solar, wind, waves and others. The problem of renewable sources that is unexpected and have intermittent nature. This thesis contain modeling of Photovoltaic renewable energy system to produces maximum 10 KW/h. Moreover, the study contains modeling of wind energy system to produces 14 KW/h. Reducing the effect of the intermittent nature of renewable sources on the electricity generation is a challenging task. The end of the project are proposed a hybrid modeling of both the PV and the wind systems by using DC link using Matlab 2017b Simulink software. The case study suffer huge shortage of electrical power production. The maximum power is 24 KW/h obtained using hybrid system. The demonstrated system as standalone or grid off system due to targeted the rural electrification. The resulted hybrid system noticed that it's improve the power and the under worst case which the system tested on it the battery can charge and the system ready to extra load.

# ABSTRAK

Tenaga amat penting untuk pertumbuhan dan ekonomi sesebuah Negara. Peningkatan amaran global dalam penggunaan bahan api fosil untuk penjanaan elektrik memainkan peranan penting bagi meningkatkan permintaan untuk menggunakan tenaga yang boleh diperbaharui bagi menghasilkan tenaga elektrik. Tenaga yang boleh diperbaharui ialah tenaga yang diambil daripada sumber yang boleh diperbaharui seperti angin, ombak dan lain-lain. Masalah sumber yang boleh diperbaharui ini ialah ianya tidak dapat dijangka dan bersifat intermiten atau tidak tetap. Kajian ini mengandungi model sistem tenaga yang boleh diperbaharui iaitu PV (photovoltaic) untuk menghasilkan tenaga maksimum 10 KW/h. Selain itu, kajian ini juga mengandungi model sistem tenaga boleh diperbaharui iaitu angin untuk menghasilkan 14 KW/h. Mengurangkan kesan sifat intermiten pada sumber yang boleh diperbaharui untuk penjanaan elektrik adalah tugas yang mencabar. Untuk itu, projek ini mencadangkan pemodelan hibrid bagi PV dan sistem angin dengan menggunakan DC link. Sistem ini telah dimodelkan dan diuji menggunakan perisian Matlab 2017b Simulink. Sistem ini berdasarkan negara Iraq sebagai kajian kes akibat kekurangan besar dalam pengeluaran tenaga elektrik di negara tersebut. Kuasa maksimum yang dihasilkan ialah sebanyak 24 KW/h diperoleh dengan menggunakan dua sumber yang boleh diperbaharui secara serentak. Sistem yang ditunjukkan adalah sebagai sistem mandiri atau sistem grid berdasarkan kepada sasaran elektrik luar bandar. Rekabentuk hibrid yang dicadangkan menepati dan berjaya dengan dapat menampung lima buah rumah di kawasan luar bandar yang sukar disambungkan ke grid negara.

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| | | |
|---|---|---|
| PV | - | Photovoltaic |
| HRES | - | Hybrid renewable energy source |
| PMSG | - | Permanent magnet synchronous generator |
| H | - | Hydrogen |
| NiMH | - | Nickel metal hybrid |
| MPPT | - | Maximum power point tracking |
| WT | - | Wind turbine |
| SOC | - | State of charge |
| IGBT | - | Insulator gate bipolar transistor |
| AC | - | Alternator current |
| DC | - | Direct current |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

For progress of country, utilizing resources and producing energy have a significant role because it is core requirement for industries, agriculture, commercial purposes. The demand for energy is growing day by day [1]. The main resources of energy are coal, fossils, oils and other gases. But there are restrictions on using these resources because of its dangerous nature and dangerous to environment. There is need of clean energy sources due to global warming and pollution in atmosphere [2].

Nowadays all emphasis is on Eco green energy which is producing energy deprived of damaging environment. In that case we have choice of renewable energy sources [1]. Renewable energy is certainly refilled on a human timescale like sunlight, wind, rain, tides, waves, and geothermal heat [3]. Renewable energy rely on natural situation such as solar rely on the weather like if it cloudy atmosphere then it's hard to rest on single renewable energy source as individual energy resource, in this circumstance the tendency of mix energy system has been progressed in previous decade and it caught great consideration from investigators .

The Hybrid Renewable Energy Systems (HRES) is comprised renewable and conservative one energy source each or can contain more than one sources of both renewable and conservative energy. HRES is becoming attractive for individual power generation in inaccessible locations because of the advances in renewable energy machineries and power automated tools and converters to transform the lenient power produced from renewable sources into valuable power.

The significant characteristic of HRES is to mix renewable power generation tools to have preeminent practise of their effective features and to find competences more than that might be attained from a solitary power source. Hybrid systems can address restrictions of fuel flexibility, effectiveness, consistency, productions and finances [4]. Hybrid energy system is an outstanding clarification for electrification of distant countryside areas and where the grid allowance is challenging and not inexpensive. Such system integrates a grouping several renewable energy sources like wind energy, solar photovoltaic, micro-hydro and may be conservative producers for backup [5].

Solar-Wind hybrid Power system is the joint power producing system with wind turbine and solar energy panel. It also contains a battery which is used to stock and supply the produced energy. This system can function as individual energy system. Both units can produced power when both sources are accessible. By facilitating the battery which will be not interrupted the power supply is probable when both sources are indolent [6].

As Iraq is facing huge shortage of electrical power in recent years [7], so this cause inspired me to conduct my study in this area.

## 1.2 Problem statement

Traditional power plants that depending on burning fossil fuel has many Environmental impacts like emission of $CO_2$ and $NO_x$ that contribute in Environmental pollution nevertheless the fossil fuel effect economically in countries due to the Unequal distribution in the world's [8]. Notwithstanding that the fossil fuel has one more problem that in many countries the major of people live in rural area that isolated , so the electrification of areas in very difficult and costly [9].

On the other hand, the renewable energy sources have its own problems. Instability and inconsistent are the main problems of the renewable sources PV that know as solar cell it's converting the sun irradiance to electrical power, it's fully depending on sun irradiance only it efficiency decrease to least in cloudy days and night . While wind is affected by the varying of wind, in other words individual PV or wind standalone systems have not been Efficient enough to fed household [10].

Hence, elimination of mention problems suggested by hybridizes of photovoltaic system and wind turbine system. PV system can reach its top during the day hours mean, while wind turbine can process day and night. Battery banks used to support the system during absence of renewable sources. The system operate during day and night and hybridize are reduced the effect of varying the climate.

## 1.3 Objectives of the project

The main objectives this projects are the following:

i. To model standalone a Photovoltaic to produce maximum 10 KW/h , a wind to produce maximum 14KW/h and a hybrid systems photovoltaic wind power systems based on Iraq as case study.

ii. To simulate the Photovoltaic , the Wind and the hybrid energy systems by using Matlab Simulink software

iii. To compare the performance of Photovoltaic, Wind and hybrid energy systems.

## 1.4 Project Scope

The project scopes are the following

i. The project is about modeling and implementing Photovoltaic system to product maximum 10KW by using sw280 PV cell due to its high stability. More over the project scope is modeling and simulation of Wind system renewable energy base PMSG generator to produce maximum power 14Kw. Nevertheless the hybridization process of PV wind renewable energy system by using DC link.

ii. The project focusing on modeling all system as standalone due to the fact that system targeted the rural areas means all the system contain battery type hybrid nickel metal due to its high capacity and long lifespan in capacity 6.5Ah.

iii. The project focusing on the climate of Iraq and the availability of renewable sources (sun irradiance and wind) and to what extent we can apply this system in Iraq

iv. The last focusing of the project is on Matlab software A2017b and how to implement the system by using Matlab software. Noticing that the result of the project has been done by using only simulation due to the small time to do the project and high cost of it

## 1.5 Project Outline

The project contain of five chapters. Chapter one include the background which is introduction to the renewable energy and the generation. Nevertheless chapter one comprises explanation to the problem statement of project tries to solve. Also the chapter contains the objectives of the project and finally the project includes the project scope.

Chapter two of the project include background and theory of the systems such a PV cell, a wind turbines, generators, Add to study to the Iraq climate.

Chapter three contains the methodology of the project's objectives. This Chapter contain the modeling and the simulation of the PV , Wind and Hybrid power systems.

Chapter four that contain the results PV, Wind and Hybrid systems such as the systems Voltage , Current and Power.

Finally the project includes the conclusion and suggested future work in chapter five

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In this chapter the work of different authors conducted in previously this area is discussed. Studying existing literature is necessary for doing any research efficiently.

## 2.2 Previous researches

For collecting rational info about renewable energy resource capacities of the country, a detail study for making hybrid energy systems were necessary. Numerous examination actions for the appeal of energy selections that are renewable are revealed for accessing of this energy resource capacities and stand-alone hybrid systems. The subsequent work of several authors were shown for a series of hybrid systems at various eras, locations and diverse nations.

According to Nfah & Ngundam & Vandenbergh (2008) [11] imitation of an individual power creation for the distant areas in Cameron was showed. The research work shown the energy necessity especially in areas such as rural places for basic needs e.g. light production and transmission, radio and other entertainments on television. The range of the energy request is about 0.2 to 1 kWh/day. They pretended and presented models for 4 diverse system structures for example; (micro hydro-diesel generator-battery), (hydro-LPG generator-battery), (solar-LPG generator-battery), (solar-diesel-battery). Consequences of models shows that, the price of energy for diverse renewable energy preference was created to be 0.296 €/kWh for micro hydro hybrid system. The small mini hydro system verified as inexpensive selection for the Cameroon (southern portions) at a lowest rate of streaming i.e. 200litter/second, however the PV hybrid was the inexpensive in these areas of Cameroon. A study conducted by [12] defined the strategy to deliver electric and energy to a model community of 100 families, hospitals and schools. The study began by examining solar and wind sources of potential contents. For this arrangement, net NPC and COE is $103,914 and 0.302 $/kWh correspondingly and the diesel fuel spent is 1,955 liters per annum for a renewable portion of 84%, consequently it turns around 633 hours/year.

To delivers power to the rural areas in Ethiopia, a viability test led by [13] was conducted for an individual solar/wind based hybrid energy process. This work discussed the recreation of PV/wind/diesel and battery to provide power and voltage request for 200 families. The paper presented the most expense proficient mixture which is crossbreeding of diesel generator/battery and converter having no involvement of sources segments which are renewable. Other price operative mixtures of diesel generator/PV and converter were also offered by them; in this case the policy and tactic practiced was the load ensuing approach. The decision of the author is feasible to organize the above specified electric energy arrangements in the zones specified assets. In [14] the author discussed that for Saudi Arabia about off grid Wind/Diesel generator hybrid power systems were used to provide energy for expenditures in the hot shore areas of Dhahran.

Two models are approved in the case study conducted in India by [15] for Sundargarh, first was conducted with a mixture of wind/solar PV and diesel generator and the second was with a mixture of wind/PV/small hydro and diesel generator. The researchers in their work also recommended that the power variation of wind and differences in domestic request are the solitary limitations manipulating the system. Elhassan, et al [16] defined the strategy and application of well-organized energy (renewable) motorized system for domestic usages in Khartoum in Sudan. The reproduction action was been achieved for the distinct families and roundabout for almost 10 to 15 families. To finalize several prices, distinct home CODE is about 49.5 SP/Wh, for 10 households. S.Rehman et al. [17] offered the viability examination of mixing turbine to the present off grid power plant of diesel in Saudi Arabia. The analysis were fundamentally done to alleviate ecological effluence and for reducing the running cots of diesel producer. Compassion examination was also completed by considering sensitive factors like velocity of the wind which can disturb the lifetimes of the power systems.

A research work conducted by [18] to estimate possibilities for off-grid electric transmission process in the rural areas in Bhutan. The examination was conducted in four areas in country. The foremost goal of this study was to enhance mixture power producing elements. PV/battery power producing system was considered to be inexpensive equipment for Gasa and Lunana. Operation of wind/battery system was enhanced for applying it in Yangtse site. The study was led [19] to enhance a wind turbine to present power plant of diesel schemes to diminish petroleum ingesting. . The practicability of the systems (hybrid) guaranteed at wind velocity of 5.48m/s, lowest renewable portion 0% and $0.162/liter petroleum price. Kasukana, et al [20] examined the practicability of hybrid renewable electric systems as primary energy necessity for portable telephone places in Congo. In three different places, the study were conducted and not linked to the grid such as like; Mbuji-Mayi, Kabinda and Kamina. The probable arrangement of different styles as shown in many studies are; diesel generator, PV-wind turbine and pure PV arrangements were configured..

## 2.3 Solar Energy

Sun is the primary and major source of every kind of energy in the earth. Per hour, 174 trillion kWh of energy is delivered to the earth by sun. We can say that, the earth capture total power of $1.74 \times 10^{17}$ w from the sun [21].

Features of the sun include: weight is $2 \times 10^{30}$ kg, beam length of around 700.000 km, age is around $5 \times 10^{9}$ years. The external sun temperature is nearly 5800 K while the temperature of its internal is around 15.000.000 K. More temperature responses is because of the conversion of hydrogen in helium. The procedure of the nuclear synthesis, which is considered from the reaction $4{}_{1}^{1}\mathrm{H} \rightarrow {}_{2}^{4}\mathrm{H} +$ as a result of extremely high temperature of the sun, Energy is being produced. The bulky volume of energy produced constantly. For each hydrogen atoms of one gram, the calculated ratio that is transformed to He sun emits energy equal with U=$1.67\times10^5$ kWh. Electromagnetic heat is the cause of solar energy emitted to the universe [22].

The calculated distance of 150,000,000 km is noted from the sun and is positioned and rotates around in elliptic path. The velocity of 300,000 km/sec cross the aforementioned distance, it expended almost 8.5 minutes. Actinic of emitted radiation is detached by the aster to the space and the force of radiation J, is designed by the equation below:

$$\boldsymbol{J = P/4\pi d^4} \tag{2.1}$$

P is the power (electromagnetic radiation) while d is taken for the distance from the centre of sun. It is calculated that thirty three percent of the radiation is returned. Remaining of the energy is captivated and reprocess to universe and the earth transfer merely energy as it collects and generates a balance of energy.

### 2.3.1 Theory of Photovoltaic

Photovoltaic or photovoltaic cells are used to produce electricity using sun rays of the sun. In the middle of the 20th Century, the progress of these cells were affecting quickly. In 1883 selenium solar cell was introduced by Charles Fritts, however the productivity of these cells were noted to be lower than 1%. The price of early marketable productions were high and fairly little competence in the range of 5 to 10% nearly. Crystalline material like crystal silicon (c-Si) were used in the construction of the solar cells [22].

At the current phase, the crystalline silicon cells has got the finest competence in 24% for photovoltaic cells used in arena of atmosphere technology and attained general competence in the range of 14% to 16% for specially manufacturing and native use. The price will be inexpensive if they are bought in bulk amounts [23].

### 2.3.2 Photovoltaic Structure

The cells construction of photovoltaic is pretty open. It contains of six unlike coatings of constituents as presented in Figure 2.1. First, efficacy consumption of photons is growing because of the support glass surface with black cover. The replication damages of the photons are decreased which is lower than 5% by the anti-reflective covering. The velocity of transmission and total distance covered by Photons were reduced by interaction grid and that's why it is capable to touch semiconductors. Finally, the back connection is paying for the well transmission[24].

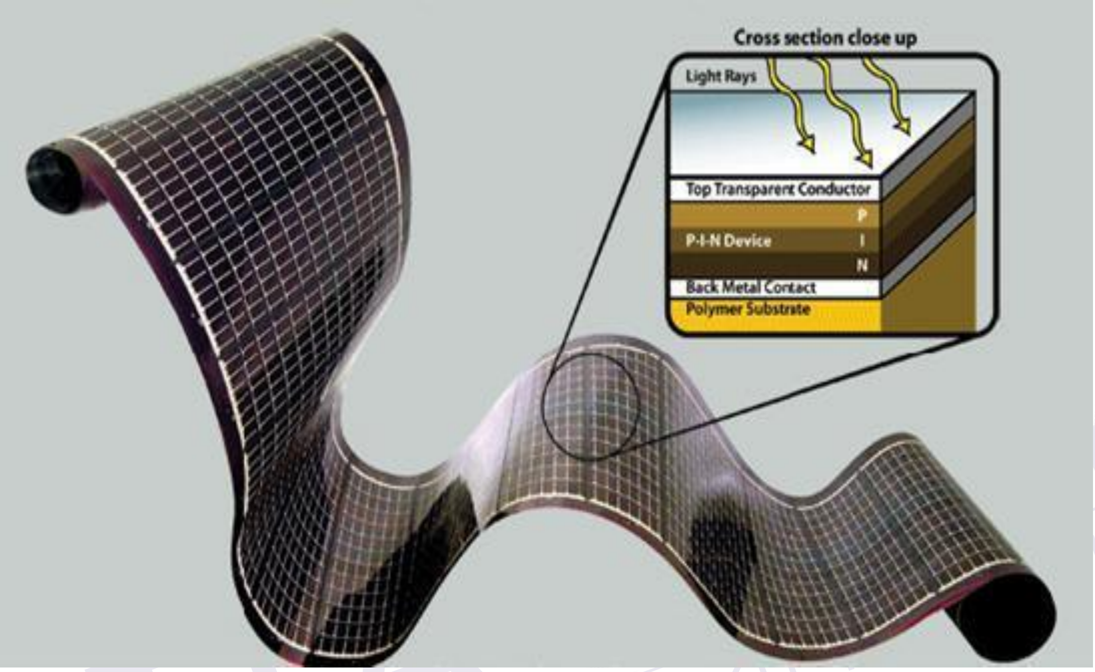



Figure 2.1: Basic structure of a generic silicon PV cell

### 2.3.3 Semiconductors p-n type

The photovoltaic cells that mentioned previously consist of 2 semiconductors p-n which are both made of crystalline silicon. The n-type semiconductor is created when some of their atoms of the crystalline silicon are replaced by atoms of another material which has higher valence band like phosphorus. Consequently an n-type semiconductor is being created which has a surplus of free electrons in its valence band. On the other hand a p-type semiconductor is created when some of the atoms of the crystalline silicon are replaced by atoms with lower valence like boron and the result is the creation of another material with deficit of free electrons and is known as p-type semiconductor. These missing electrons are called holes.

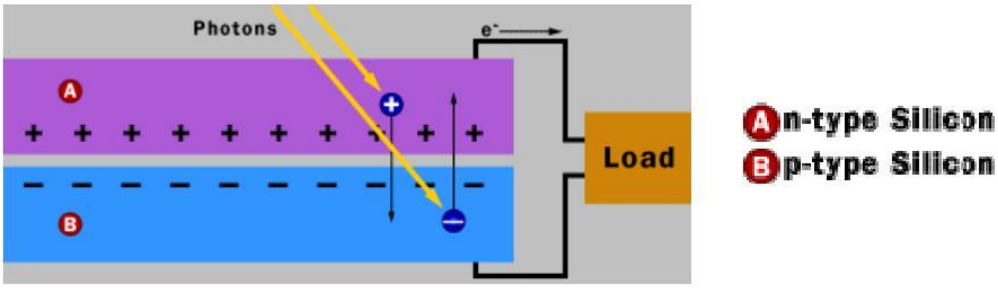



Figure 2.2: Operation of a PV cell

P-n junction is formed with semiconductors attached and depletion region become created through generation of electric field. From figure 2.2, one can see that how electron move from one semiconductor to other and diffusion process occur. The process shows that how different charge atoms move in different directions inside [24].

### 2.3.4 Photovoltaic Effect

Photovoltaic outcome generation is due to sun light beam. Electrons move when the photovoltaic cell photons uncovered to light beam of sun. The electrons then start moving conduction band after it begin to move quickly. Holes of adjacent p-side are attached to the electrons coming from reverse direction which is n-side.

The current inside photovoltaic cell is generating when electrons from one semiconductor start moving to another semiconductor. Moreover, the open circuit conditions come when the current is reached to zero, the resistance increase too much or infinite and the voltage extents extreme rate. Else, the short circuit will occur if the current reaches maximum value while the resistance become zero. Maximum power point (MPP) of Photovoltaic cell is shown in the Figure 2.3[25].

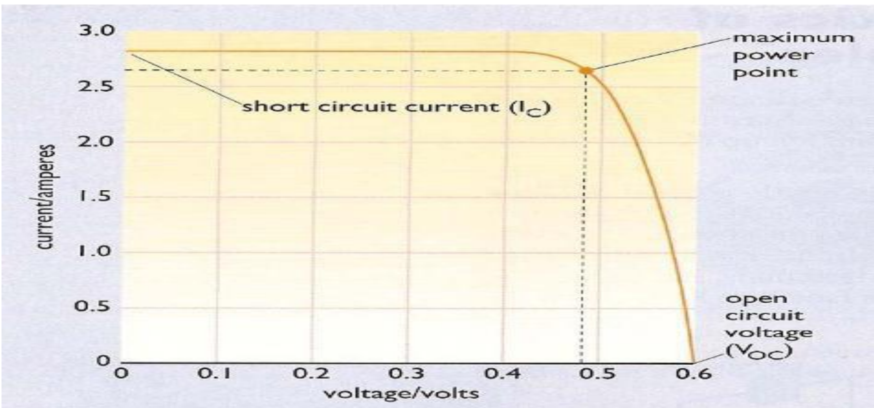



Figure 2.3: I-V curve of a typical silicon PV cell under standard test conditions

Finally, international standard test conditions are established, in order to measure the power output of photovoltaic cells. The level of irradiance is defined as 1000 W/m², with the reference of air mass 1.5 solar spectral irradiance distributions and cell junction with temperature of 25°C. [24]

### 2.3.5 Main Cell Types

Silicon is mainly used in the construction of photovoltaic cells. Silicon can be found inside the sand in the form of silicon oxide ($SiO_2$). The photovoltaic cells of silicon are categorized in four sets, dependent on the construction and structure. The types are:

i. Single-Crystal Silicon: Monocrystalline silicon is used in this type. First, silicon is washed and clean then start melting it and then crystallized into ingots. The effectiveness of cell fluctuates in the range of 13% to 16% and it is branded high cost for the production with dark blue colour[22].

ii. Polycrystalline Silicon: The size of this type is big normally. Its competence oscillates between 10-14% [24].

iii. Ribbon Silicon: Its productivity is nearly 13% and is very costly with manufacturing construction in limits [24].

iv. Technology which makes use of solar cells of thin size normally with the total width of a semi-conductor is nearly 1µm. By means of multiple connections this type of photovoltaic cells achieves extreme productivity. Moreover the Productivity of silicon cells are not reduced in high temperature. [22]

### 2.3.6 Main Parts of a Photovoltaic System

In the Figure 2.4, photovoltaic system is consisting of various devices. The complete photovoltaic system is constituted by inverter, charge controller and batteries.

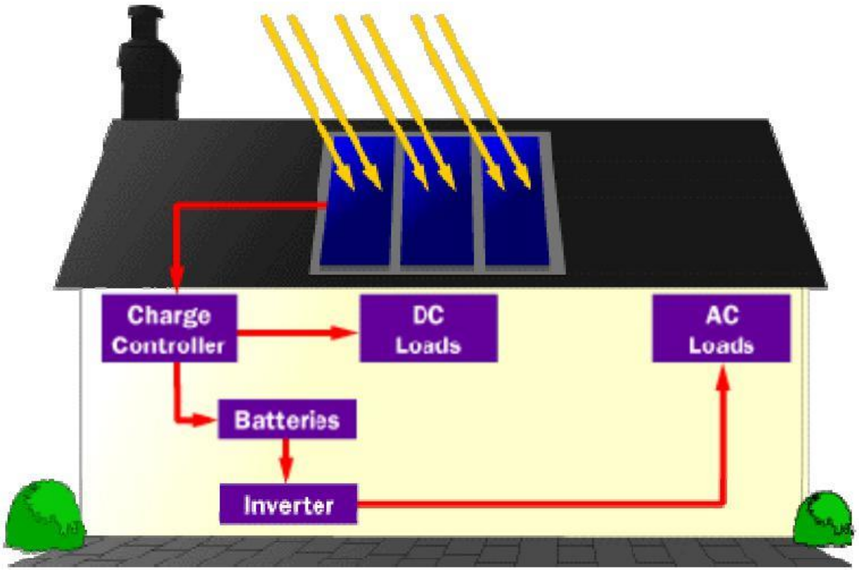



Figure 2.4: General schematic of a residential PV system

The energy from Photovoltaic cell is maintained inside batteries. Deep-cycle batteries are common type of batteries that are typically used. Nickel-cadmium type of battery that is quite costly, But as compare to lead-acid battery, it is quite advance in terms of its discharged level with more strength [30].

It is compulsory to discuss the features of the batteries before the photovoltaic system is connected to the network: The stated features are discussed as:

i. Battery total capacity demonstrate the entire capacity which is the maximum energy that is possible that can be stored inside the battery.

ii. Battery voltage is stated based on the electrolyte type and the number of factors.

iii. Discharge complexity signifies that the battery release level which is proficient to attain on daily basis.

iv. The price per kWh signifies that the entire electrical energy to be considered while the batteries providing the power throughout the cycle of life.

v. The battery has to be substituted after 5-6 years process due to limited lifespan of the battery.

vi. The temperature at which it operates shows that battery capability is decreased as temperature decreases and vice versa.

Charge controller is a key instrument for the battery life cycle. When charge controller is in process mode, the life cycle of battery will be reduced if battery is overcharged. For maximizing the battery lifecycle, the charge controller will not allow the electrical load uninterruptedly to flow when the batteries are entirely charged [26].

The inverter is a key instrument that transform (Invert) alternative current (AC) from direct current (DC). Using of AC is vital and critical because it is extensively applied for all diversity of manufacturing segments and national practises and normally used in cases where a basis of constant electric voltage is distributed and alternative voltage is considered for using. The effectiveness of the inverter is moderately high and fluctuates between 93% and 96% [27].

A photovoltaic cell is infrequently used as single separate set, as it is not able to deliver adequate power which is necessary.

A characteristic photovoltaic system comprises 36 distinct 100 cm² silicon photovoltaic cells and supplementary expedients lead-acid batteries have voltage of 12 V. The organization system has the capability of generating around 13V in cloudy days and charge battery up to 12 V[28].

In efficient operation and using system more, it is compulsory to realize that it can perform during several electrical loads associated in the system. As mentioned before, I-V curve reflects the behaviour and describes a photovoltaic cell. Every element of the photovoltaic cell can be identified with I-V curve as given in Figure 2.5[22].

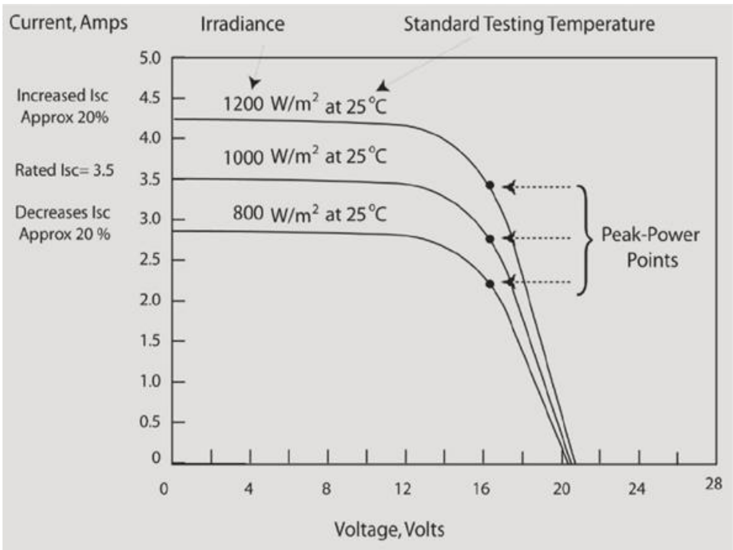



Figure 2.5: I-V curves in different intensities of solar irradiance

In actual circumstances, the action of a photovoltaic system may be diverse due to alterations of solar radiation intensities over a period of time. When their comes variations in photovoltaic cells light, which transfers an electrical resistance, the power point moves. Meanwhile when the resistance value is change, variations can be noted in current and voltage with suitable capacity instruments; ammeter and voltmeter. The maximum power PV that can yield from the cell, is found as:

$$P_{max} = I_{max} \times V_{max} \tag{2.2}$$

From maximum power and the suitable I-V curve, the fill element can be find which is the vital element in assessing behaviour of a PV cell. As the fill factor values are closer to the unit 1, the effectiveness of the system behaviour will be amplified.

$$FF = (V\_max \times I\_max)/(I\_sc \times V\_oc) \tag{2.3}$$

To find electrical power, $P_{out,}$ the total solar irradiance $G_{total,}$ and, and the efficacy of the electrical conversion $\varepsilon_E$ must be estimated. The solar radiation which touches the earth has two dissimilar modules; the beam emission and the diffuse radiation [28].

$$G_{total} = G_{beam} \times G_{diffuse} \tag{2.4}$$

The conversion is given by formula :

$$\varepsilon_E = E_{stc} \times 1 - \left[P_p\left(T_{module} - T_{reference}\right)\right] \tag{2.5}$$

Where

$$E_{stc} = \frac{P_{max}}{G_{total} \times A} \text{ measuring in standard conditions.} \tag{2.6}$$

A is the floor area of the panel.

$$P_p = \frac{power\ drop\ off}{P_{max}} \tag{2.7}$$

Thus as to compute the power produced from a PV element, the resulting equation used is:

$$P_{out} = G_{total} \times A \times \varepsilon_E \tag{2.8}$$

Similarly the power ingoing to the system can be find with the formula 2.9:

$$P_{in= \tau\alpha \times A \times G_{total}} \tag{2.9}$$

And the system's power loss from the element can be find with the given formula:

$$P_{loss=U \times A \times (T_{module} - T_{air})} \tag{2.10}$$

Where U is the overall heat transfer coefficient (W/m2*K)

From the above estimated values, the valuable power supply from a PV cell can be resultant from the equation:

$$Q_h = P_{in} - P_{out} - P_{loss} \tag{2.11}$$

The efficiency of the electrical power productivity from a PV cell and the effectiveness of a PV system can be estimated as follows:

$$\frac{P_{out}}{P_{max}} \times 100\% \; (Effectiveness) \tag{2.12}$$

$$\frac{(P_{out}+Q_h)}{P_{in}} - 100 \; (efficiency) \tag{2.13}$$

Then, the PV module photo current is given by:

$$I_{ph} = [I_{sc} + K_i(T - 293)].\frac{G}{1000} \tag{2.14}$$

Where is $I_{ph}$ is the light generated current in a pv module (A) , $I_{sc}$ is the PV short circuit current at 25° C and 1000 w/$m^2$ , K is the short circuit current temperature co-efficient at $I_{sc}$ =0.0017A/°C , T is the module operating temperature in Kelvin , G is the PV module illumination (W/$m^2$) = 1000 W/$m^2$ .

Module reverse saturation current, $I_{rs}$ is given by:

$$I_{rs} = \frac{I_{SCr}}{[exp^{(\frac{qV_{OC}}{NskAT})-1}]} \tag{2.15}$$

Where q is electron charge = 1.6 x $10^{-19}$ C, $V_{OC}$ is the open circuit voltage, N is the number of cells connected is series, K is Boltzmann constant = 1.3805 x $10^{-23}$ J/k

A=B is an idealist factor = 1.6,

The module saturation current $I_o$ fluctuates with the temperature of the cells, which is specified as:

$$I_o = I_{rs}[\frac{T}{T_r}]^3 \exp[\frac{q.E_{go}}{B_k}\left[\frac{1}{T_r} - \frac{1}{T}\right] \tag{2.16}$$

Where $T_r$ is the reference temperature = 298K, $I_o$ is the PV module saturation current (A) $E_{go}$ is the band gap for silicon = 1.1 eV

The current output of PV module is

$$I_{pv} = N_p.I_{ph} - N_p.I_o[\exp\left[\frac{q.(V_{pv}+I_{pv}R_S)}{N_sA_kT}\right] - 1 \tag{2.17}$$

Where $N_p$ is the number of the cells connected in parallel, $V_{pv}$ is the output voltage of a PV module (V); $I_{pv}$ is output current of a PV module (A), $R_s$ is the series resistance of a PV module. Equation (2.14) – (2.17) are used to develop the PV module

### 2.3.7 Advantages of PV Systems

Photovoltaic units can certainly enter in distant zones as the current that yield originates from a trustworthy, not effluence and autonomous source which is sun. Economically photovoltaic systems can be reasonable, as it might support in a huge degree the sustainable development of a region). Photovoltaic systems were developed for performing and functioning in inauspicious circumstances and it and possess lighter weight. It is likely fitted on floor or ground of constructions where sun light rays can influence on the photovoltaic cell surface certainly [29]. The primary benefits of PV systems include the following:

i. An extensive lifetime
ii. No cost for operation
iii. Less inconsistency of system productivity and highly consistent outcomes.
iv. Maintenance rate is less.
v. No sound contamination action period.
vi. Energy preservation.
vii. Retain atmosphere fresh and away from contamination of the $CO_2$ releases in air.

A photovoltaic system is fitted with a peak power production of about 1 kW; in a year's period operation can save around 1300 kWh of electrical energy and 800 kg of $CO_2$ emission. [24]

## 2.4 Wind Energy

Wind energy form of the energy which is renewable and comprise of the procedure of transforming the wind kinetic energy to electricity[30].

### 2.4.1 Wind

Wind is the unceasing transfer of atmospheric air masses and is find by its velocity and direction. This direction originates from its variation and the changing values of the environmental density because these values are the consequence of the solar warming of diverse portions of the surface of earth. Even though environmental air blow in all directions, only its horizontal drive is really deliberated as wind [21].

The wind energy originates from the air as a consequence of its measure which is shown in Figure 2.6. Wind energy is the adaptation of a minor fraction, nearly 0.2%, of the solar radiated ways that spreads on the exterior of the earth. The wind power around the globe is calculated around 3.6×109 MW whereas, based on association of the legal approximations of the world weathercasting, the fraction which is existing for energy manipulation in numerous portions of ecosphere is merely 1% and it is predictable to be around 0.6Q (175×1012 KWh) [31].

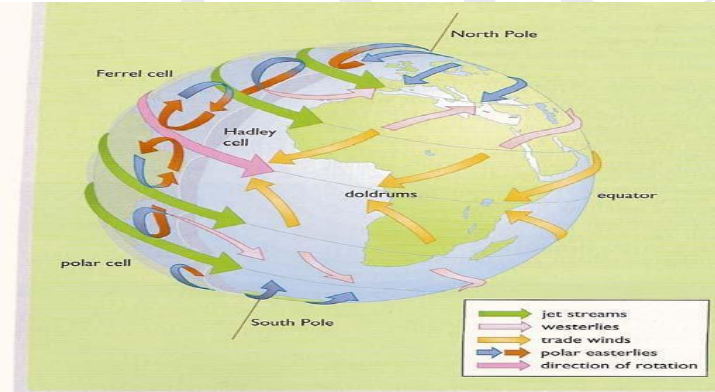



Figure 2.6: The global wind circulation

Numerous experts are agree that the appropriate misuse energy of the wind can be determined in a manner the crises of energy of the world. For example, the energy requirements there scarcely establish 0.1% of wind energy prospective of the whole country. Currently 59,100 MW of the total wind produced of volume is mounted round the world, with an normal yearly development of 29% in the past ten years as it is understood from Figure 2.7. Thus wind energy can't be simply expected neither can its unceasing process. Wind possess small mass, approximately which indicates that big arrangements have to be ready for its misuse [32].

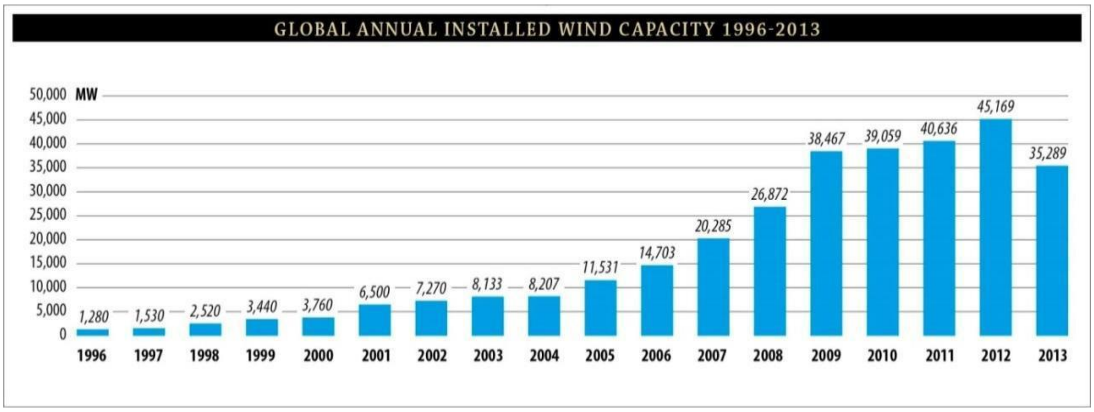



Figure 2.7 : Worldwide installed wind capacity the last 17 years [33]

Certainly the extensive practice of the wind energy and its well-organized misuse is balancing the global energy deprived of overburdening at the same time the atmosphere with hazardous gases.

### 2.4.2 Theory of Wind Energy

The mistreatment and misuse of energy of wind is as ancient since the human is present on the Earth. It had a significant character in the mortality's development usually in marine, irrigation and agricultural.

In marine ships, men has used wind energy in past. Adding to this, ancient and archaeological intelligences said that Chinese and Egyptians. Also used wind technologies wind energy in 5000 B.C whereas Chinese used to drive water using windmills in 200 B.C [34].

In Europe, it is supposed that windmills seemed merely earlier 1200 AD and were moved by the supporters on their method back. The preliminary verified reference was in 1185 AD [31].

In era of dark periods, windmills seemed in Holland, Spain, France, Italy, and in Portugal. They were used for the water pumping in Holland from zones that were situated in lower than sea side level. Additional type of windmill which was extensively used during the revitalization era was windmill that was slow and multi bladed as shown in the Figure 2.8 [31].

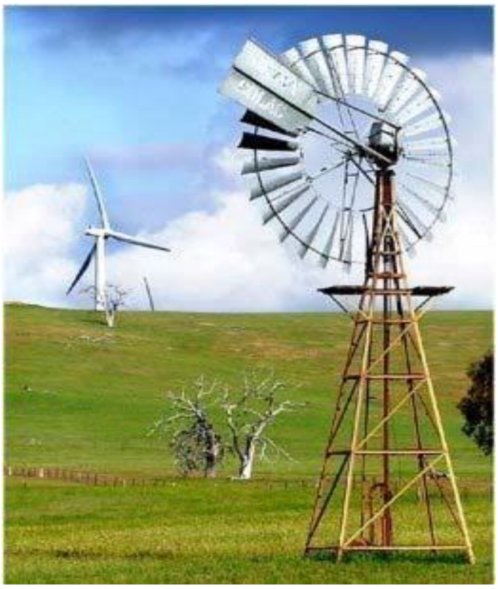


Figure 2.8: A multi-bladed wind turbine

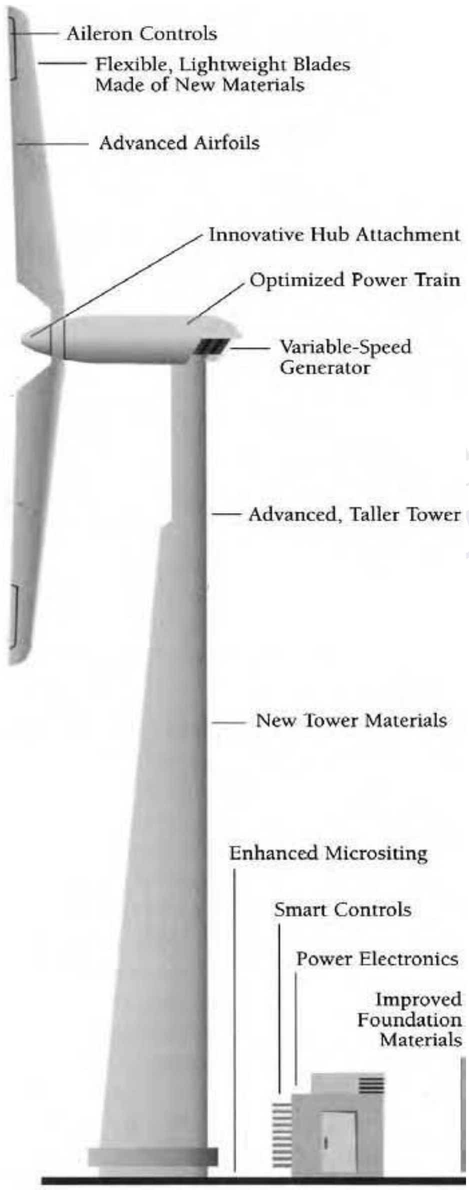
In the start of the century the Danish generated electric power using wind, whereas in windmills in USA with construction of metal was the base for electricity generation too. Since 1870 till 1930 Chicago became the largest manufacturing centre for windmills generation with an expected generation around 6 million units over that period. Turbine of winds were functioned in Denmark through experiments with 2 electric producers with 22.8 meters thick rotor blade in the observation of professor P.La.Cour in 1891. Lastly in 1940 a wind turbine with two blades was factory-made in the Vermont in U.S.A which was regarded at 1.25 megawatts in winds of around 30 mph. [35].

In the current decade that monitored after the Second World War, using of atomic energy along with the little amounts of the oil expressively restricted the attention for the misuse of wind energy. Though the ecological contamination and the energy disaster made the industrialized states to express a severe attention for this uncontaminated and earliest energy source [32].

### 2.4.3 Wind Turbine

Wind turbines are used to generate wind power from flowing air to generators of mechanically power for electricity production. Wind power, as an substitute to burning vestige oils, is abundant, usually dispersed, can be renewed, fresh, yields no greenhouse gas radiations when it is in action of process while it ingests no water, and uses slight land [36] . The preliminary windmill to produce electric power in the countryside U.S. was fixed in 1890 [22].

The average turbine magnitude of wind fittings was 300 kW till the early 1990s. New machines were put in the 1- to 3-MW range of total capacity. Wind turbines with capacity of 5-MW are completely established and are in test process in some countries, containing the U.S. Figure 2.7 is a theoretical design of a current multi-megawatt wind tower appropriate more for uses of utility-scale [37] .




***An artist's concept of a next-generation utility wind turbine is shown here.***

Figure 2.9: Modern wind turbine for utility-scale power generation.

There is noted a declination in enhanced turbine projects and plant operation budgets from 35 cents/kWh in 1980 to 3 to 4 cents/kWh in 2004 at constructive sites. On this price, wind energy has developed as the minimum cheap novel source of electronic power and which is lower in cost as compare to coal, oil etc, and challenging old-fashioned sources on its specific financial value. Therefore, it has come to be pretty economically to conveniences and electronic companies, with 30% evolution in period of 1993 to 2003. Universally, around 40,000 MW of capacity wind has been fitted, and additional 100,000-MW capacity by 2010 is being expected [22].

### 2.4.4 Wind Turbine components

A wind turbine is a technology which transforms the kinetic_energy of the winds into electrical_energy . Each turbine consists of the subsequent constituents:

i. Tower construction

ii. Rotor having two to three blades involved in the hub

iii. Shaft with automatic gear

iv. Generator of electronic power

v. Yaw machinery like the tail vane

vi. Devices for sensing and control

### 2.4.5 Wind Turbine Types

Wind turbines divided into categories based on the positioning of their axes in direction wind flow. There are several categories of present turbines that are famed in the given two categories: horizontal and vertical axis turbines. [38]

Latest wind turbines have high speed and low rotation speed rotation ones, this is defined as the proportion of the velocity of the margins of a windmill rotor to the velocity of the free wind, and is shown below.

$$\lambda = \frac{\omega \times R}{v} \tag{2.18}$$

ω is the angular velocity in which is measured in rad/sec while R is the rotor radius and measured in meters while the measurement unit of velocity is meters per second.

The inter-joining of the turbine with the electric grid shows a significant part as whole of the current inter-linked wind generators to the grid yield electronic current which have the frequency of the central grid [31].

Lastly the constraint of solidity, it is used to discriminate turbines of wind. Solidness is typically stated to be the fraction of the range of the rotor that comprises material rather than air [25].

For horizontal axis machines it is stated as:

$$\sigma = \frac{z \times c \times R^2}{\pi \times R} \tag{2.19}$$

For vertical axis machines it is stated as:

$$\sigma = \frac{z \times c}{R} \tag{2.20}$$

Where parameter σ is the solidity of the turbine, z is the number of the blades, R is the radius of the rotor and c is the chord (width) of the blade.

The mechanical power $P_m$ in the wind is given by the rate of alteration of kinetic energy i.e.

$$p = \frac{dW}{dt} = \frac{1}{2}\frac{dm}{dt}v^2 \tag{2.21}$$

Where $d_m / d_t$ is the flow mass

#### 2.4.5.1 Vertical Axis Wind Turbine (VAWT)

There is huge difference between vertical axis turbines and traditional wind turbines because in vertical axis wind turbines, the main axis is perpendicular to the floor.

Their arrangement and organization makes them perfect and suitable bot for rural and urban locations and deals the proprietor a chance to counterbalance the increasing price of electric energy and to keep the environment more reserve. Also, they don't have any necessity of the complex head machineries and instruments of conservative horizontal axis turbines [38].

Direction of the wind doesn't not affect VAWTs which is useful in areas where the there is a frequent variation in wind direction. VAWTs are well capable to produce turbulent air flow which is established in constructions and other places. This state is further and more in cities of people living. VAWTs are perfect for rural as well as urban uses which include installations of roof top.

Other devices like generators can be fixed and started on the ground level, which make it easier to install or retain. VAWTs is no dangerous for birds and wild life, as due to its slow motion and extremely visibility. VAWTs can be considerably not as much of costly to shape.

#### 2.4.5.2 Savonius Turbine

Savonius is a category of VAWT where rotor is fixed and was presented by Finnish engineer S. J. Savonius in 1922 and are said to be one of the simplest turbines. It is fundamentally consists of two cups or half drums fitted to a middle channel in differing ways of direction. Both cups and drums fetches the wind and move and circulate the shaft, carrying the opposite cups or drums in a movement of the wind. The process is repeated by cups and drums, to circulate the shaft and finalizing a complete circulation. This procedure remains for the whole of time the wind blows while the shaft rotation is used to start and move a pump [39].

These kinds of windmills are usually used for wind instruments of quite fast speed like the anemometer. Modern Savonius machineries have grown into grooved bladed parts, which possess greater effectiveness, competence and minor vibration as compare to older twin cup or drums [31].

## 2.5 Power Electronic Circuits

In converting electrical energy, Power electrical devices are used. Power converter is required to transform alternating current (AC) to direct current (DC). The transforming is achieved through solid-state semiconductor instruments that functioned through switching On and OFF conditions at specific frequency [40]. Thus, power electric converter which is basically switching converter is managed and controlled with the help of switches.

### 2.5.1 AC/DC Rectifier

Hart (2007) has discussed purpose and role of rectifier i.e. transforming alternating AC to DC with power diodes or by regulatory the firing angles of well-regulated switches. The full-bridge, three-phase, AC–DC rectifier is presented in Figure 2.8. The output average DC voltage is given by:

$$V_{dc} = \frac{3\sqrt{2}}{\pi} V_L cos\alpha \tag{2.22}$$

Where

$V_L$ = line-to-line voltage on the three-phase AC side of the rectifier and

$\alpha$ = angle of firing delay in the switching.

The delay angle is calculated from the zero crossing in the positive half of the AC voltage wave. Equation 2.22 displays that the DC voltage output

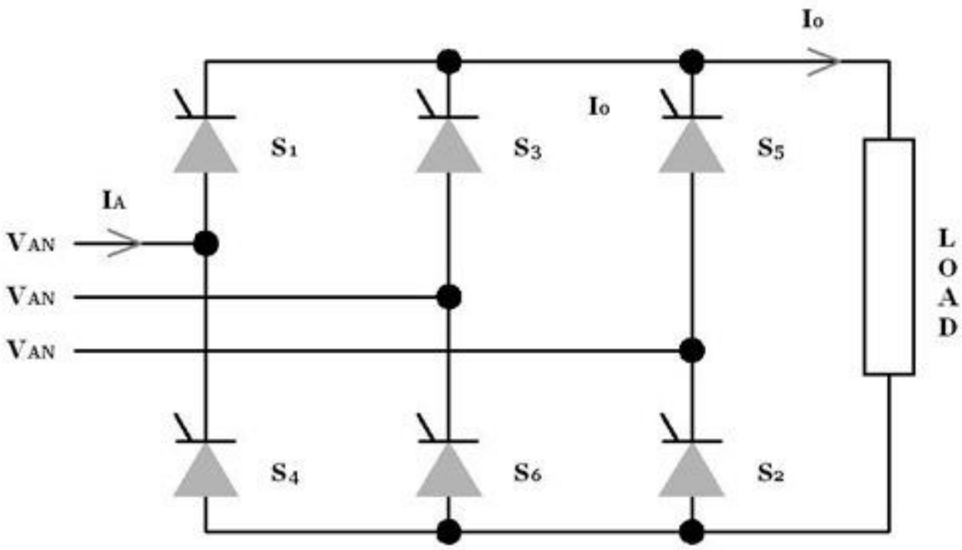



Figure 2.10: Three-phase, full-bridge, AC–DC controlled rectifier circuit.

By varying the delay angle α, this in turn controls the conduction (on-time) of the switch. [22]

A harmonic filter is so required to diminish the some of the AC portion of the voltage at output and to make the DC portion to increase more. An L–C filter fixes this using inductor that is linked in series and a capacitor in parallel for rectification of voltage in output. The load fixes the DC-side current as:

$$I_{DC} = \frac{DC\ load\ power}{V_{DC}} \tag{2.23}$$

In steady-state action and process, the steadiness of power should be preserved and sustained on both AC and DC i.e. the power on the AC should equivalent to the sum of the DC load power including the damages in the rectifier circuit. The AC-side power is thus:

$$P_{AC} = \frac{DC\ load\ power}{rectifier\ eiffiency} \tag{2.24}$$

The three-phase AC power is given by:

$$P_{AC} = \sqrt{3} V_L I_L COS\Phi \tag{2.25}$$

Where $COS\ \phi$ is the power factor on the AC side? With a well-designed power electronic converter, the power factor on the AC side is approximately equal to that of the load. From Equation (2.22) with Equation (2.25), we obtain the AC-side line current $I_L$.[41]

### 2.5.2 DC/AC Inverter

The DC voltage to an AC voltage is converted through invertor. DC voltage input is generally lesser in most of the cases whereas the output AC is equivalent to the source voltage of grid of which can be120 or 240 V that depends on the country.

The inverter can be constructed as separate apparatus for solar power like applications.

There are diverse forms of inverters including the switching waveform shape. These possess variable circuit arrangements, efficacies, benefits and drawbacks.

An inverter function is to convert DC power sources to AC power and is valuable in operating electronic tools and devices evaluated at the ac voltage and are extensively used in the interchanged way power deliveries inverting phases.

The basic circuits contain an oscillator, control circuit, drive circuit for the power instruments, switching instruments, and a transformer.

The transformation of DC to AC is possible with transforming stored energy of the dc source devices e.g. the battery, or from the output of rectifier, into an alternating voltage. This is possible through switching instruments that are uninterruptedly turned on and off, and then moving up with the help of transformer.

MOSFETs are used to switch on and off the DC input voltage. An alternating voltage at secondary winding is induced by the variable voltage in primary. The transformer function as an amplifier to rises voltage output at a ratio estimated by the turn's ratio.

Push-pull half-bridge, Push-pull with centre tap transformer, or push-pull full bridge are the three Inverter output steps normally used. The push pull with centre tap is highly common due to its easiness and, certain outcomes; still, it have a denser transformer with low productivity and competence [42].

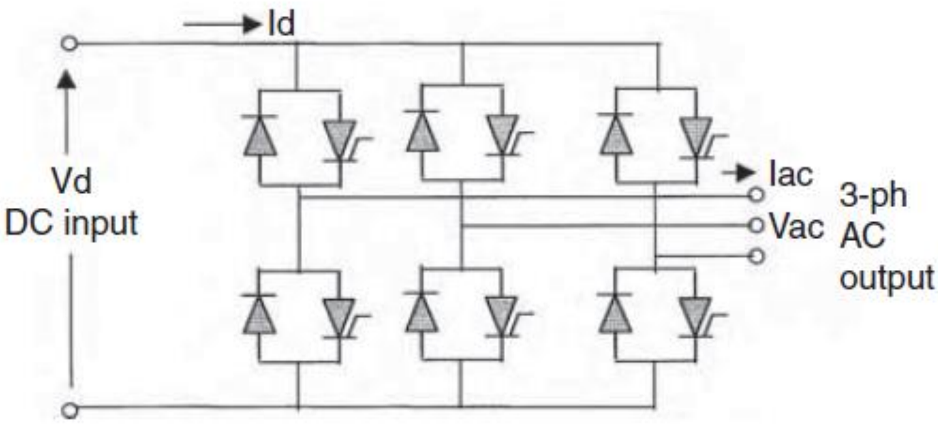



Figure 2.11: DC-to-three-phase AC inverter circuit.

Figure 2.11 displays the DC-to-three-phase AC inverter. The fundamental frequency (60 or 50 Hz) phase-to-neutral voltage is given as:

$$V_{PH} = \frac{2\sqrt{2}}{\pi} COS(\frac{\pi}{6}) V_{dc} \tag{2.26}$$

The line-to-line AC voltage is given by $\sqrt{3}.\, V_{PH}$ [22].

The inverters are categorized on the waveforms in output with the three types.

The square wave has a little quality power as compare to the rest ones. The adjusted square wave delivers an improved power quality (THD~ 45%) and is appropriate for maximum electric apparatus and devices.

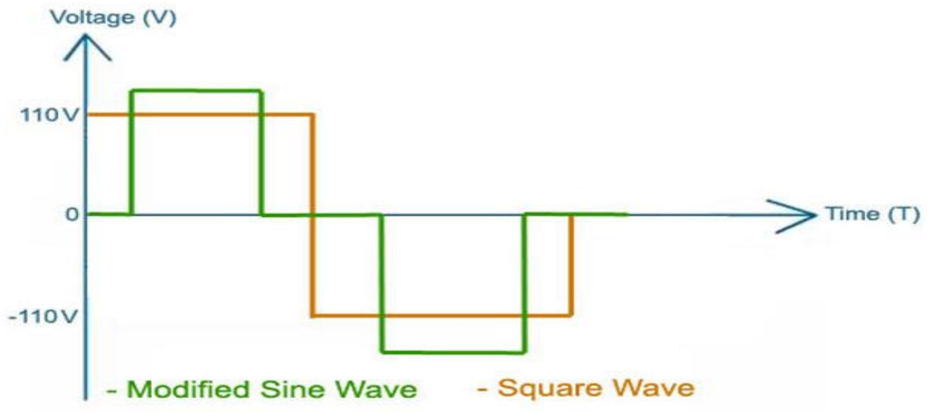



Figure 2.12: inverter modified sine output waveform

The true sine wave inverter generates waveform with THD of around 3% which is the lowest one [43].

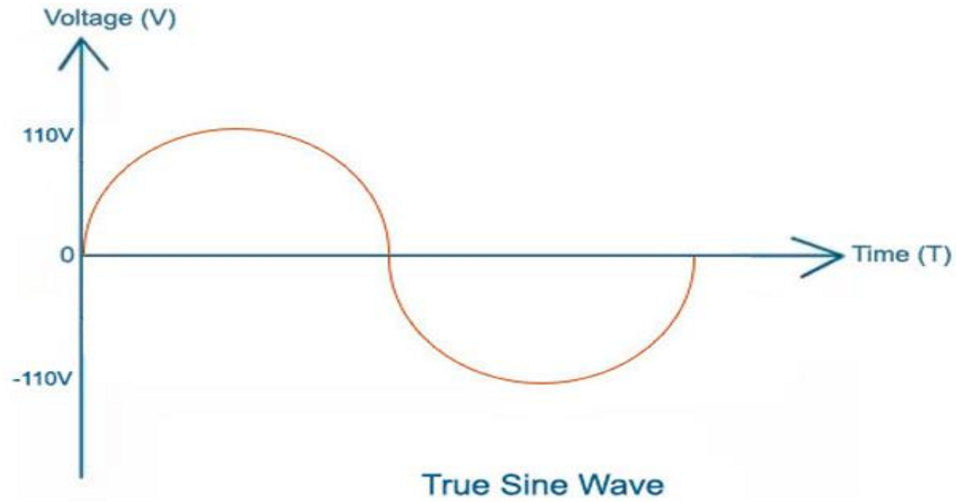



Figure 2.13 inverter pure sine output wave form

## 2.6 Batteries

Battery is a an electronic device and transforms chemical energy to electricity [44]. Lithium ion and the lead acid battery are most common types of batteries used now days. The lithium ion is primarily used in convenient electronics containing a cell phone or laptop as they can supply a very big quantity of electric power in a very minor battery. Still, they become very expensive when generated in quite big sizes because of the resources and complication of constructing the batteries. The lead acid battery is essentially used in such high power applications devices. It is an essential portion of the rapid storage of solar energy. Explicit systems are designed and constructed using these batteries so they can deliver electric power all the periods of time. Today maximum of the renewable energy systems make use of the batteries to do two dissimilar important functions. One include the energy storage which is generated. These applications can be seen and analysed in wind and solar energy[45].

Table 2.1: Major Battery Types for Renewable Energy Sources.

| **Battery Type** | **Advantages** | **Disadvantages** | **Common Uses** |
|---|---|---|---|
| Lead Acid | -Low Cost-Mass Produced | -Heavy-Harmful Chemicals<br>-High maintenance<br>-Short Life | -Solar Panel Systems-Wind power Systems<br>-Standby Applications |
| Nominal metal hybrid | - high capacity<br>-recycling able<br>- environment friendly | - limited lifespan<br>- required complex charge algorithm | -Electric vehicles |
| Lithium Ion | -Small Size-Low Weight<br>-High Energy Capacity<br>-Long Life | -Expensive-Difficult to Produce | -Small Electronics |
| Ultracapacitor | -High Power-Long Life<br>-Easy Storage<br>-Quick Charging | -Expensive-Difficult to Produce | -None yet |

### 2.6.1 Lifespan

For production of electricity, chemical reaction take place between certain type of lead and sulphuric acid inside the battery of lead acid and the inverse process of that charges the battery to produce original acid and lead. The construction of these forms of batteries are quite easier and they are mass shaped everywhere the sphere, creating the lead acid battery the high operational and economical battery for large power uses [44].

This battery (Lead acid) is the low price battery to use in these systems where many authors worked to understand the detail of the processes that happens inside. The average lifetime of a lead acid battery is almost 1000-2000 cycles at 70% release. The cycles are the measurement of the quantity of charge and discharge of a battery [44]. As a consequence of the chemical actions, the lifetime of the battery is significantly decreased if the battery is run completely without charge. When entirely discharged several chemical liquids inside battery are fragmented down to their extreme prospective and the procedure develops not reversible. This is known as stratification process. For maintaining the life of the battery, most of the structures only release the battery to a specific fraction before turnoff the system. It is also harmful to store the battery on a low charge for a period of time. When the battery is discharged down to 30%, electrical energy must be supplied soon to avoid sulfation [46].

Considerably overcharging of the batteries can also decrease the life time of battery. The gassing process can happen. When the sulfuric acid and lead return their original conditions while the battery is charged totally, then additional electric charge start reacting water inside the battery [46].

### 2.6.2 Charging Techniques

Particular methods for charging should be applied to the system for maximizing the life times of the batteries. Frequent and most used techniques are used to charge individual batteries includes three dissimilar portions. [46] The preliminary is an unceasing charge till the battery touches 95% of its maximum. Second phase is a float charge, where the battery is charged fully and after that is detached and used until it marks the 95% threshold. This can be analysed in

Figure2.14. The third phase of charging contains float charging at a inferior threshold to balance the cells and must be completed over a period of times. These charging methods are applied in nearly of total systems that the lead acid battery is placed into [45].

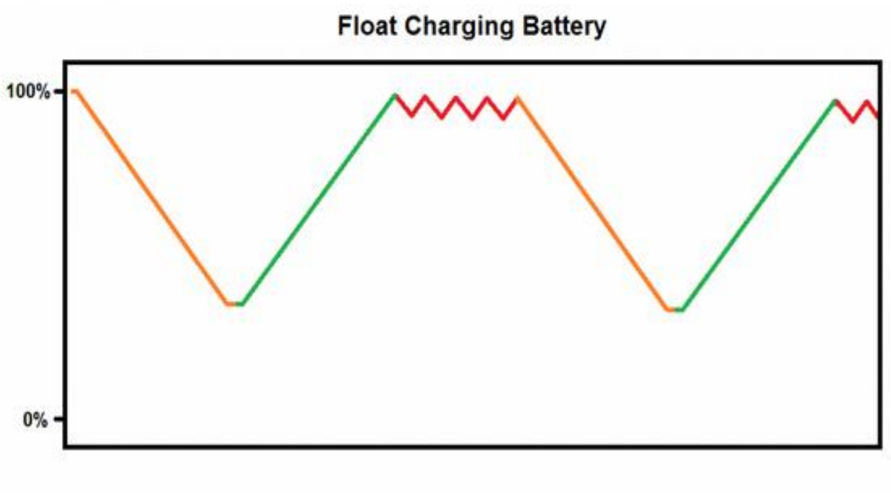



Figure 2.14: Float charging method during normal operation of a battery

### 2.6.3 Capacity and discharge

The capacity of battery is the quantity of electricity it can distribute at the rated voltage. A small cell possess lesser capacity in comparison to large ones with the similar chemistry, though they advance similar open-circuit voltage. Capacity is measured in amp-hour (A·h). The capacity of a battery is typically defined as the product of 20 hours and current that a new battery can constantly delivers for 20 hours at 68 °F (20 °C), e.g. a battery rated at 100 Ash carry 5 A over a 20-hour period keep at room temperature. The portion of the deposited electric charge that can be supplied by battery rely on several elements which include chemistry of the battery, the rate charge delivery (current), the necessary voltage at the terminal, the time period of storage, and ambient temperature.

The greater the rate of discharge, little will be the capacity. Current, discharge time and capacity for a lead acid battery is estimated are related through Peukert's law:

$$t = \frac{Q_p}{I^k} \tag{2.27}$$

$Q_p$ is the capacity when discharged at a rate of 1 amp?

$I$ is the current drawn from battery (A).

$t$ is the amount of time (in hours) that a battery can sustain.

$k$ is a constant around 1.3. [47]

Batteries that are stored for either for lengthy time period or that might discharged at a small fraction of the capacity lose capacity because of the existence of commonly side reactions that are not reversible and that consume charge transporters deprived of generating any current.

This method is called internal self-discharge. Additionally, when batteries are charged again, further side reactions can happen which reduces the capacity for succeeding discharges that occur.

Internal energy losses and restrictions at the rate in which ions pass from the electrolyte make efficiency of battery to fluctuate. Above from lowest threshold, discharging at a lower rate provides more of the capacity of battery's than at a rate of higher level. Installing batteries with variable A·h assessments have no effect on the operation of devices (though it might have effect on the interval of operation) which is rated for a particular voltage except when load limits are surpassed. High-drain loads like digital cameras can decrease overall capacity, as occurs with alkaline batteries [22].

## 2.7 Wind speed and solar radiation in Iraq

Iraq has abundant renewable energy sources qualified to be at the forefront of countries to invest this type of energy, but the cheap price and availability of fossil fuels prevented it. As countries progress in renewable energy research due to the shortcoming of fossil fuel , Iraqi researchers are turning to study to what extent this energy can be exploited and adopted in Iraq [48].

### 2.7.1 Sun irradiance

Iraq has long hours of sun irradiance of up to 3,500 hours a year. The peak sun irradiance hours it’s in summer reach to 11.7 hours per day. The average sunrise in June which is the highest average in the year 11.9 hour/day and recorded 11.8 and

11.5 in July and August respectively. The hours of sun irradiance decrease gradually in autumn season to be 10.6, 8.9 and 7.2 hours/day in the autumn months September, October and November respectively. Then the sun irradiance hours sag in winter to its lowest annual rates 6.4, 6.4, and 7.2 hours/day during the winter months December, January and February. Lastly in spring season the sun irradiance hours increase to reach 8 , 8.5 and 9.8 hours/day on the spring months March April and May as shown in Figure 2.15 [49]

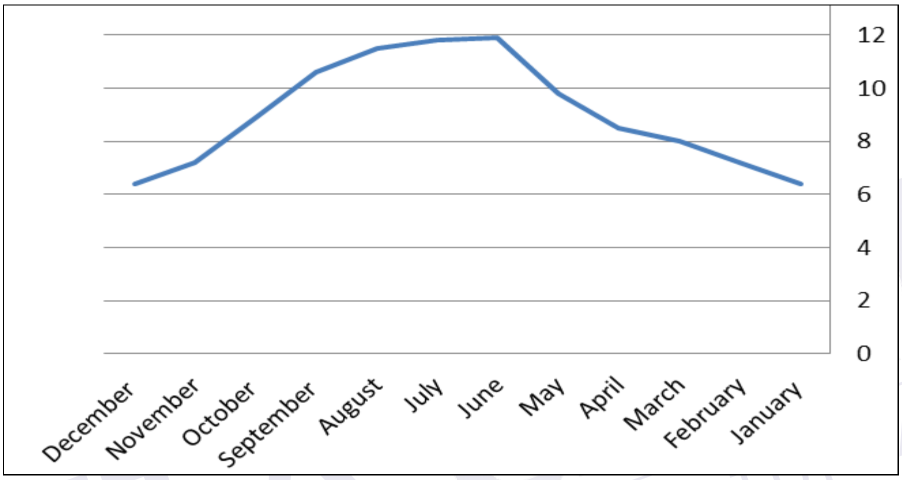



Figure 2.15: Sun irradiance hours during the year (hour/day)

On the other hand, the amount of energy that is radiant from the sun is considered high also specially on the summer season. In the summer season the power that radioactive from the sun recorded its highest average values 720.5, 709 and 639 W/cm$^2$ during the summer months June, July and August respectively. The power radioactive from the sun decrease gradually to the winter to be in the autumn season during the months September, October and November 528 , 409 and 258 W/cm$^2$ respectively then the average reach its lowest value in the winter season during the months December , January and February 258 , 286 and 376 W/cm$^2$ . The solar power that used by solar cell increase as we closer to summer as it increase in the spring season during the months March, April and May 479 , 568 and 646 W/cm$^2$ as shown in the Figure [48]

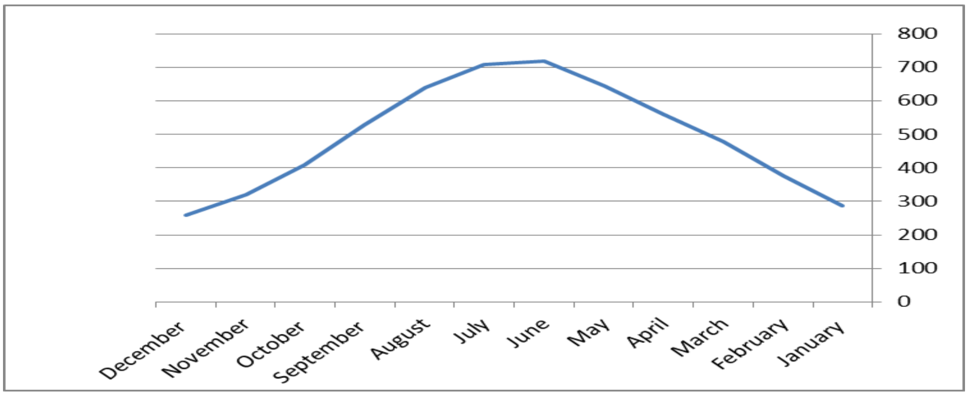



Figure 2.16: The average of power that radiant from the sun during the year ($W/cm^2$)

### 2.7.2 Wind Speed

The wind speed in Iraq looks steady when the seasons change. The highest value of wind speed in Iraq it's can be 5.9 m/s. As shown in Figure 2.17.[50]

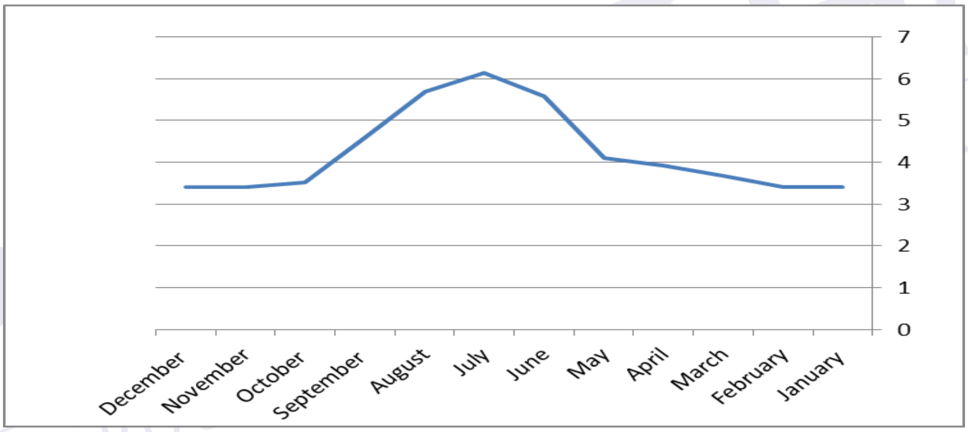



Figure 2.17: the wind speed average in Iraq during the year (m/s)

# CHAPTER 3

## METHODOLOGY

### 3.1 Introduction

This chapter includes the flow chart of the project and the methodology to achieve the goals of the project moreover all the modeling and the simulation had included in this chapter.

This contain of modeling hybrid PV-Wind all has been done by using Matlab/Simulink software. It will do through step and divided the system to arrive the last flag at the end. The hybrid renewable system contain of PV and wind as primary power generator , converters contain dc-dc , ac-dc and dc-ac , power bank , the power extension and load

## 3.2 Project flow chart

This section contain the research methodology of the thesis and the Chronological order of the thesis parts. The project firstly start with the problem statement that project tried to solve. The thesis contain also an objectives that attained to solve the problem. Nevertheless the project contain the implementing of the objective by modeling and simulation of PV , wind and Hybrid systems. Finally the thesis contain the results and their explanation of them. The Figure 3.1 shows the project flow chart.

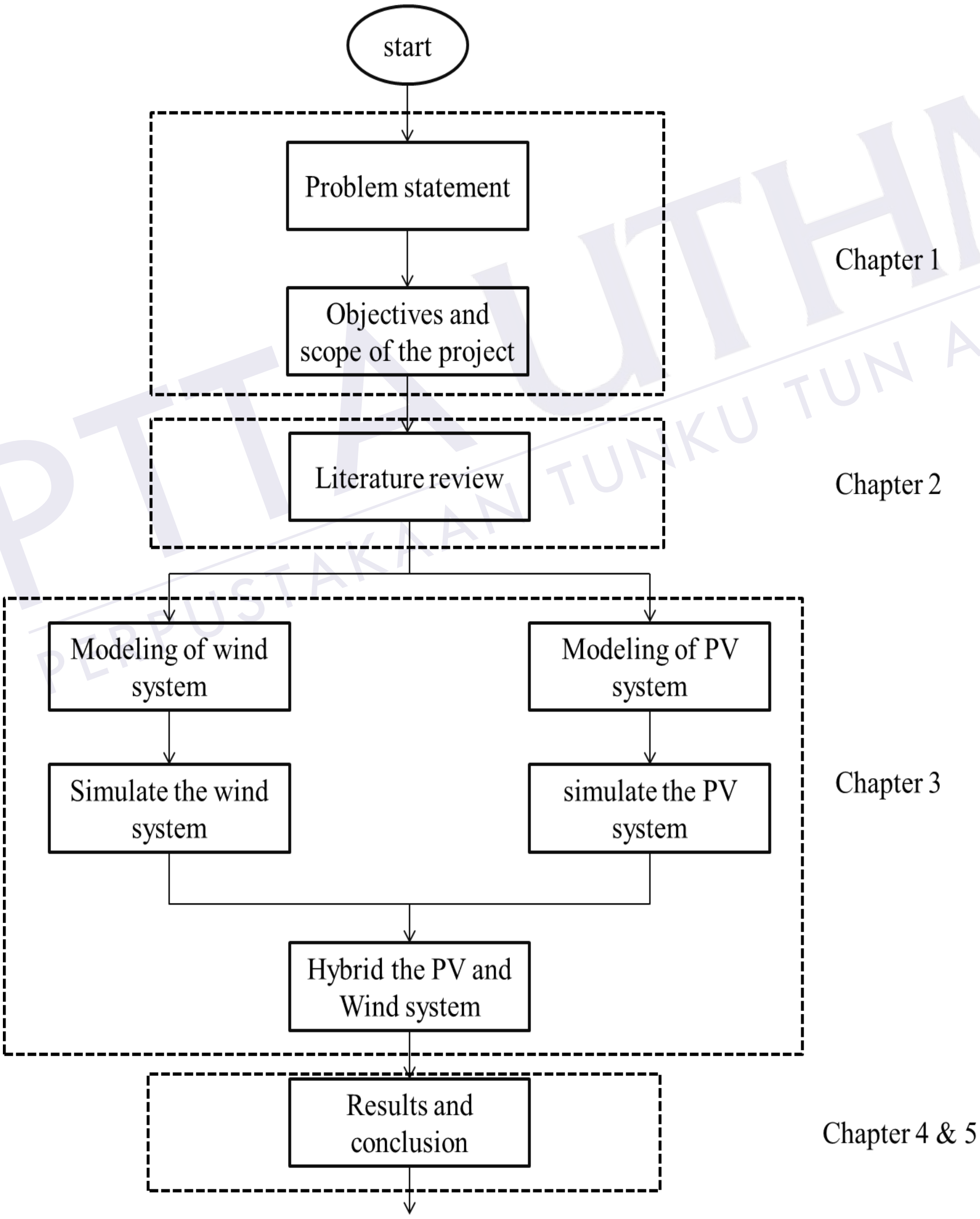



Figure 3.1: Project flow chart

### 3.3 Photovoltaic Renewable energy power system

PV system is a system that converts the sun irradiance power into electrical power. The system consists of many parts as shown in Figure 3.2.

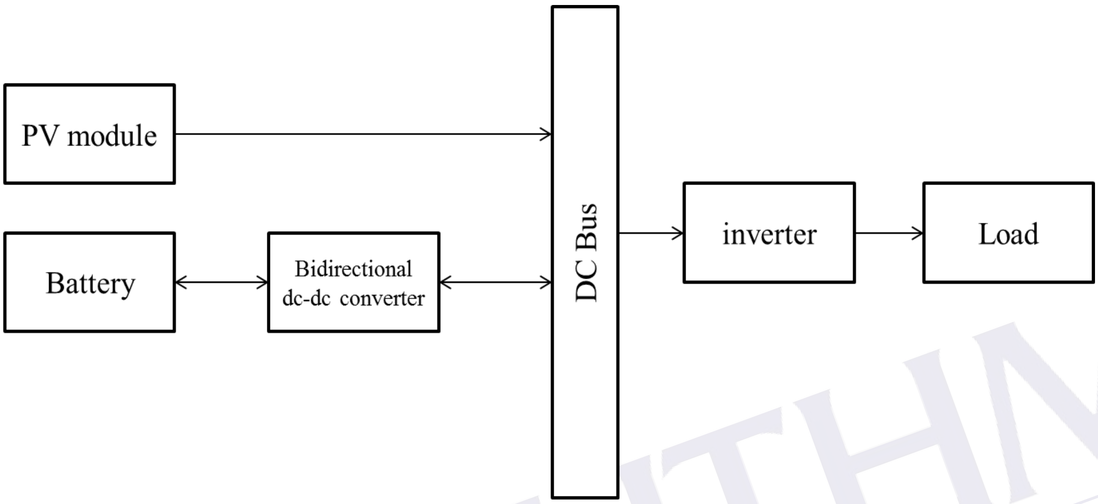



Figure 3.2: Block diagram of PV system

The system produces maximum power 10KW to fed five houses each on consuming 30KW per day[7], [51]. The system has implementing by using Matlab software and tested under database of Iraq. Figure 3.3 shows the PV system Simulink.

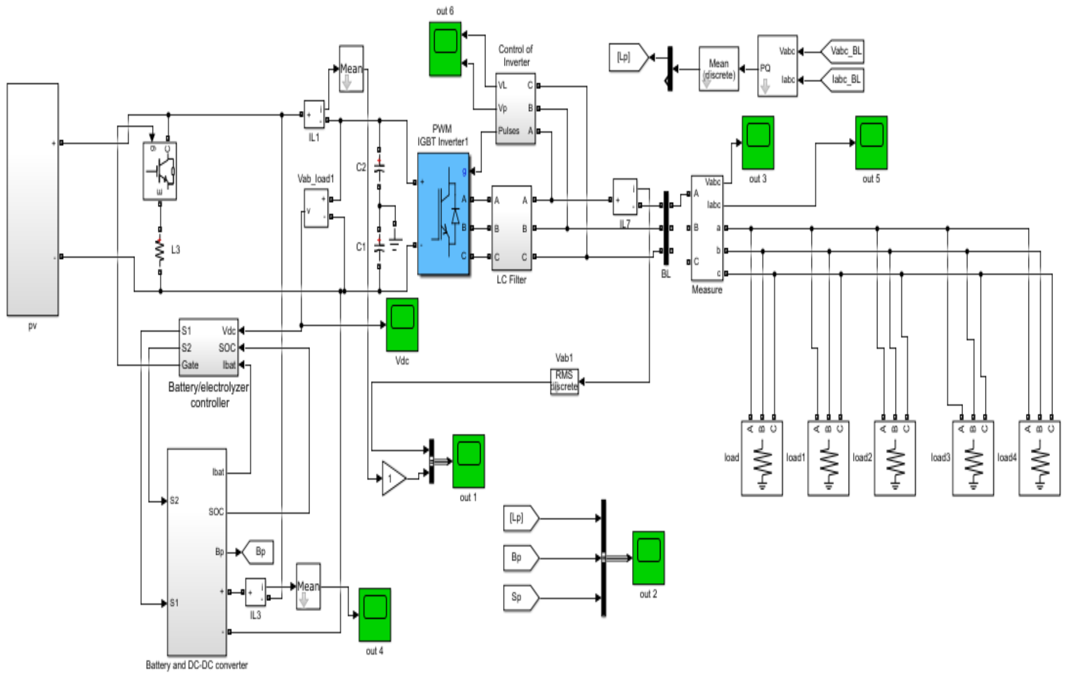


Figure 3.3: PV system Simulink

### 3.3.1 PV module

PV system consists mainly from solar PV cells. PV module contain from number of solar PV cell connected in series to increase voltage and parallel to increase the current. A solar PV cell is a simple p-n junction its equivalent circuit demonstrated in Figure 3.4. The solar cell has current source which is present the photocurrent , resistance in series to it to act as the internal resistance , parallel resistance that play the role of leakage current and diode the current supplied to the load express in the Equation 3.1 [30].

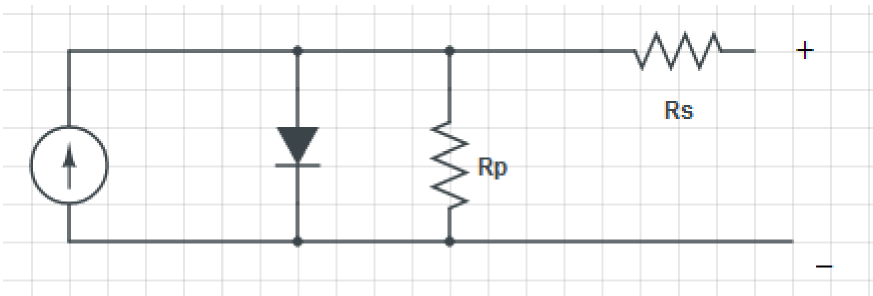



Figure 3.4: Solar PV cell equivalent circuit

$$I = I_{PV} - I_O \left[ EXP\left(\frac{V+IR_S}{aV_T}\right) - 1 \right] - \left(\frac{V+IR_S}{R_P}\right) \quad (3.1)$$

$I_{PV}$ Photocurrent

$I_O$ diode reveres saturation

V voltage across the diode

a ideality factor

$V_T$ thermal voltage

$R_S$ series resistance

$R_P$ parallel resistance

Then $I_{PV}$ can be calculation by using Equation 2.14. Reverse saturation current can be obtained by using equation 2.16. The parameter of the solar PV module that using shows in Table 3.1 under stander test condition (STC)

Table 3.1:Parameter of PV Type sw 280[52]

| parameter | Value |
|---|---|
| $V_{mp}$ | 31.8 V |
| $I_{mp}$ | 8.93 A |
| $I_{sc}$ | 9.45 A |
| $V_{oc}$ | 39.0 A |
| $P_{max}$ | 280 W |
| $K_I$ | 0.0032 A/K |
| $K_V$ | 0.1230 V/K |
| $N_S$ | 44 |
| $N_P$ | 4 |

SW 280 PV panels used in the project due to its high stability and low weight. The PV array consist of four panels, each two panels connected in parallel have connected in series. The PV system produces maximum power 10 kW/h. Many research's authors has used developed the solar PV cell by using two or three diodes to improve the accuracy and in this work we used single diode PV solar cell due to the simplicity of implement. In the simulation of PV cell equivalent circuit. each single PV module contain 48 cell which then connected PV modules to present PV array that generate total electricity of the power generated from the sun irradiance by PV system due to the small power that generated by single solar PV cell. A single PV module in the simulation present in Figure 3.5

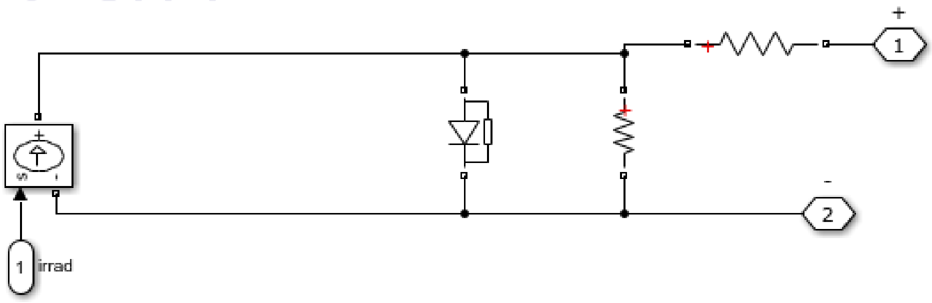



Figure 3.5: Single PV module implemented in simulation

The equivalent circuit of the PV Module is present by the Figure 3.6

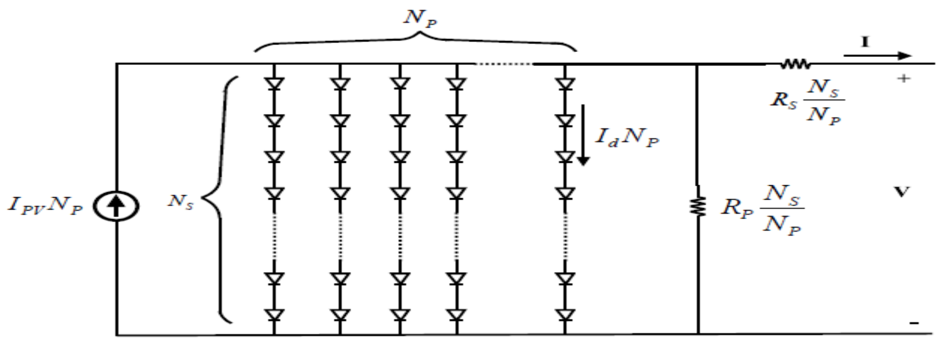



Figure 3.6: Equivalent circuit of single PV module

The Figure 3.7 and 3.8 present the connection of PV module in series and parallel respectively to present the PV module

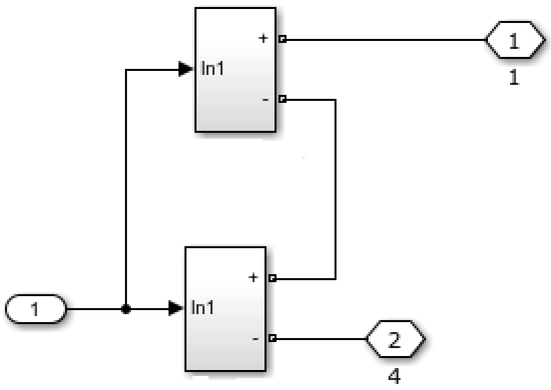



Figure 3.7: Two PV modules connected in series

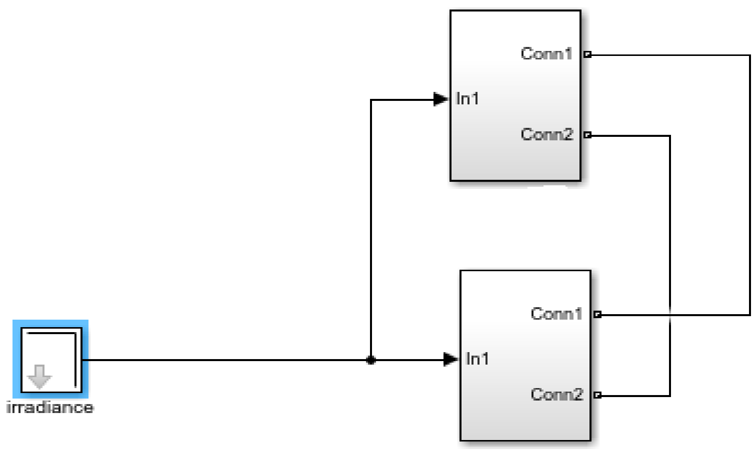



Figure 3.8: Two PV modules connected in parallel

The total of the PV array that fulfills the requirement can be obtained by the equation (2.17). Finally the Figure 3.9 and 3.10 express I-V and P-V curves on 1000 W/cm$^2$ sun irradiance

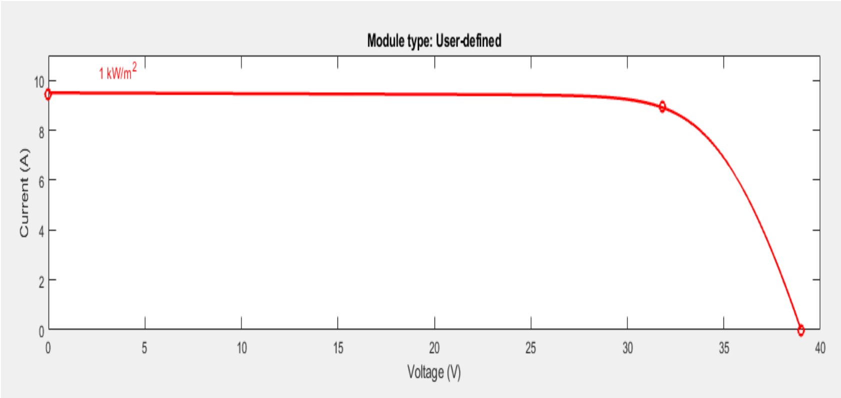



Figure 3.9: I-V curve of PV module

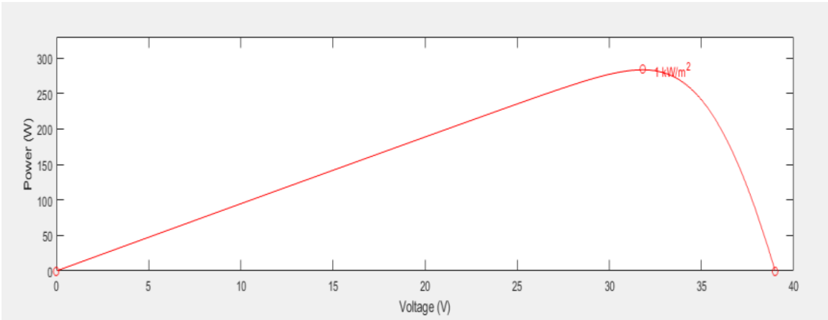



Figure 3.10: P-V curve of PV module

### 3.3.2 Battery system

Battery system contain the storage bank to use the power that save in battery, in case of absent of renewable source , control unit that responsible for the battery charging or support the PV module, and the bidirectional DC/DC converter.

#### 3.3.2.1 Battery bank

The battery used to support the PV system in absent of sun irradiance situation. The battery that used is due to its high capacity .The simulation work contain Simulink of Nickel-Metal hybrid battery that available in Matlab 2017b as shown in Figure 3.11

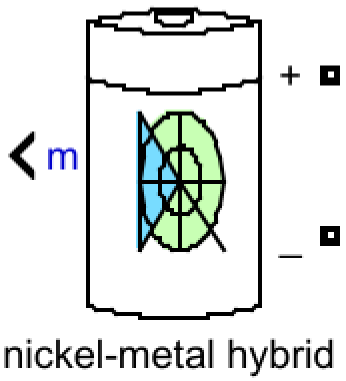



Figure 3.11: Nickel metal hybrid battery Matlab Simulink

### 3.3.2.2 Control Unit

The control unit has main function is to automatic charge or discharge battery to avoid overcharging or discharging of battery[30]. The system depending on the sensitivity to the voltage droops in the system to do two functions. The system compare between the voltage reference and generated voltage. The PI controller calculate the reference current to compare it with the battery current to on and off the bidirectional to charge or discharge [53]. As shown in Figure 3.12.

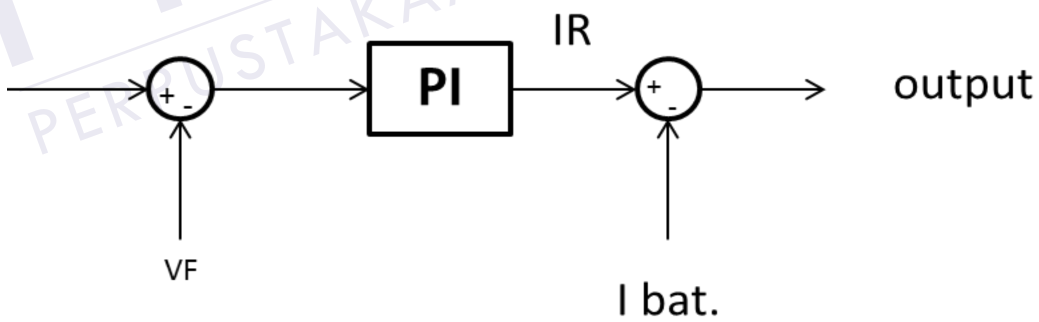



Figure 3.12: The control system

The control operate in two situations. The first one that is the voltage generated below the reference voltage which is 640 V. The bidirectional DC-DC converter process a boost converter and the battery supplied the system with power, if the state of battery charge above 20%. The second scenario that is the voltage generated above reference voltage the DC-DC converter process as buck and the battery charged. If the battery state of charge below 80%[53] . The system is done by using Matlab Simulink as show in Figure 3.13.

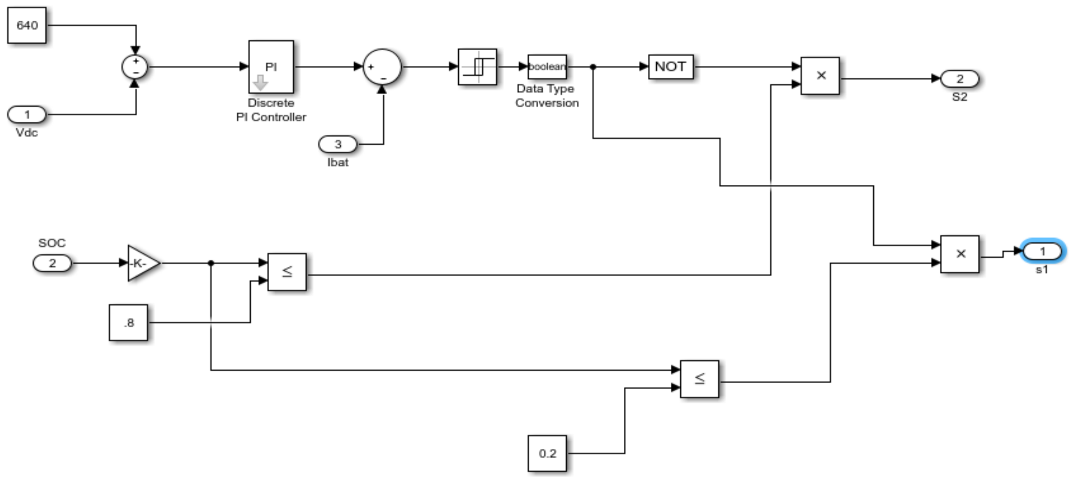



Figure 3.13: The Simulink of control system

#### 3.3.2.3 DC-DC bidirectional Converter

The bidirectional DC-DC converter is a converter that has the ability to convert the voltage level by two sides. The type of converter that used is non-isolated half bridge converter. It had used due to its simplicity and economic reasons. The Figure 3.14 shows the converter that used.

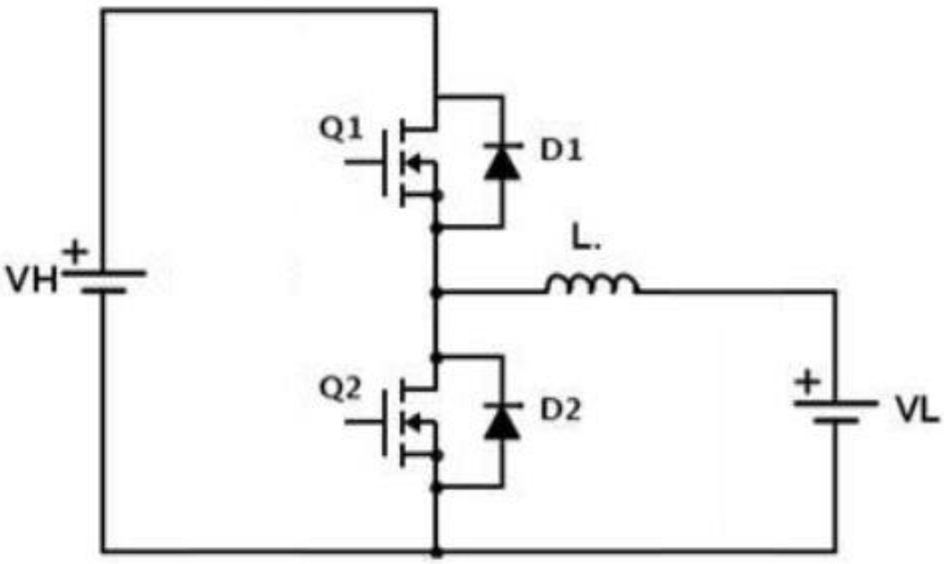



Figure 3.14: Non-isolated Half Bridge DC-DC bidirectional converter

The converter work is two modes. First one Q2 and D1 (on) , during this mode the converter act as boost convert to convert voltage level of battery (300V) into the system DC voltage level which is 640V during the battery fed the system with energy. Nevertheless the second situation, where is Q1 and D2 (on) the converter act as buck converter to converter the energy from the system into the battery using battery charging scenario[54]. The Figure 3.15 shows the Simulink of the converter.

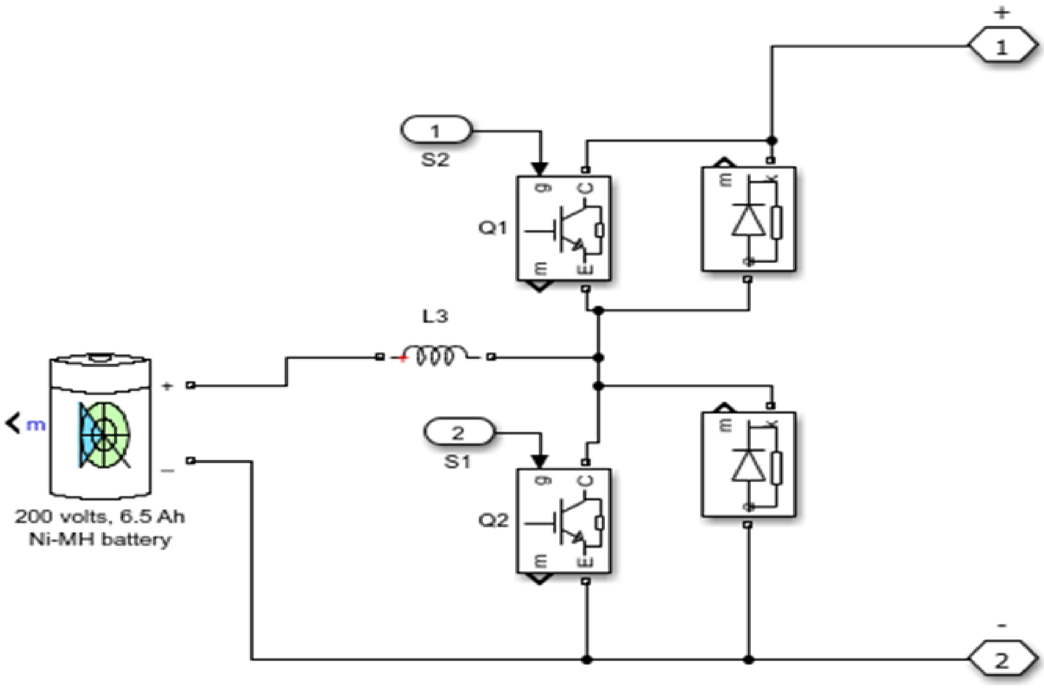



Figure 3.15:Non-isolated Half Bridge DC-DC converter in Simulink

### 3.3.3 Inverter

Inverter is a power electronic circuit that can convert the power from DC to AC. The type of inverter that had used is the Voltage Source Inverter three phase full bridge inverter base IGBT, Which used for high and medium power application. The Figure 3.16 show the circuit of the inverter [30].

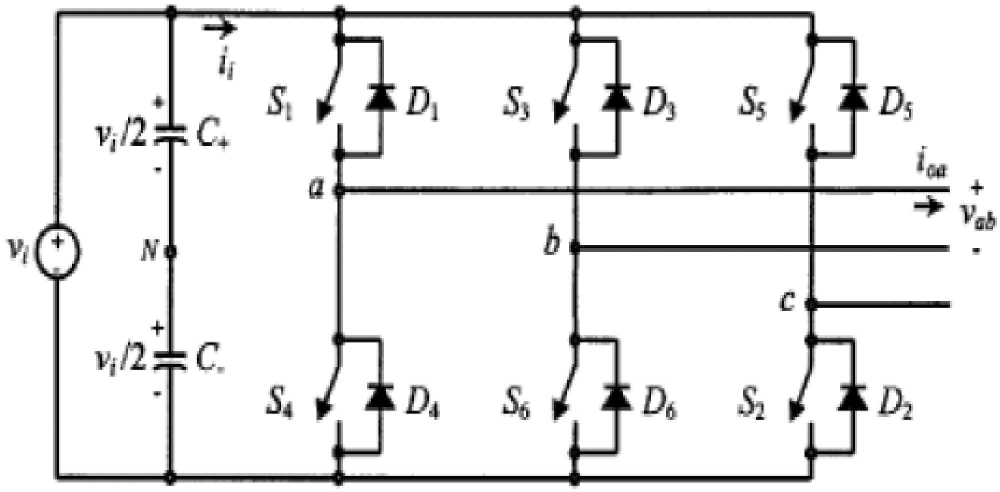



Figure 3.16: Voltage source three phase full bridge inverter[55]

It has used control for the inverter which is carrier based pulse width modulation (PWM) technique. The inverter also contain also LC filter to reduce the harmonics and produce pure AC voltage [56]. The simulation implements using the IGBT inverter three bridges that available in Matlab as the inverter shown in the Figure 3.17.

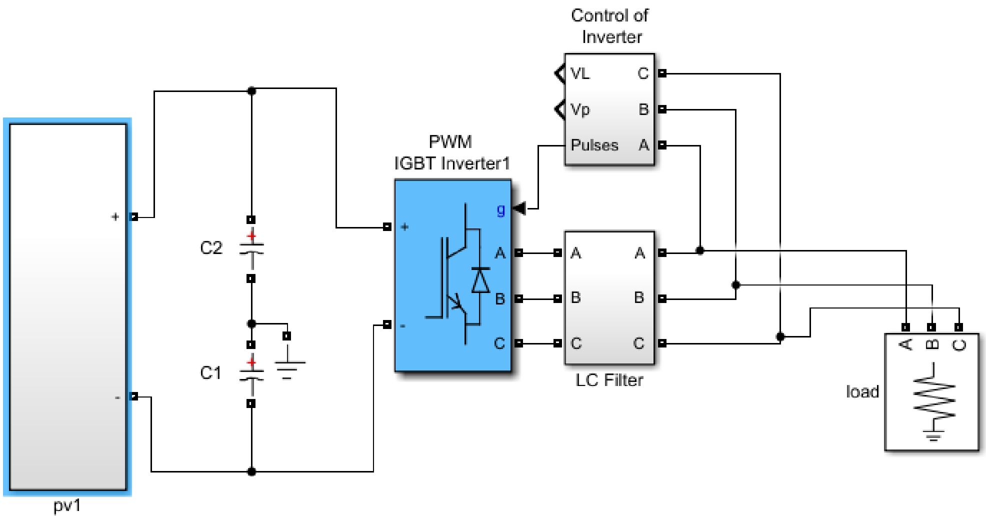



Figure 3.17: Inverter Simulink

The work contain control of inverter has been done by INDRANIL SAAKI [57]. The Figure 3.18 shows the Simulink of inverter control

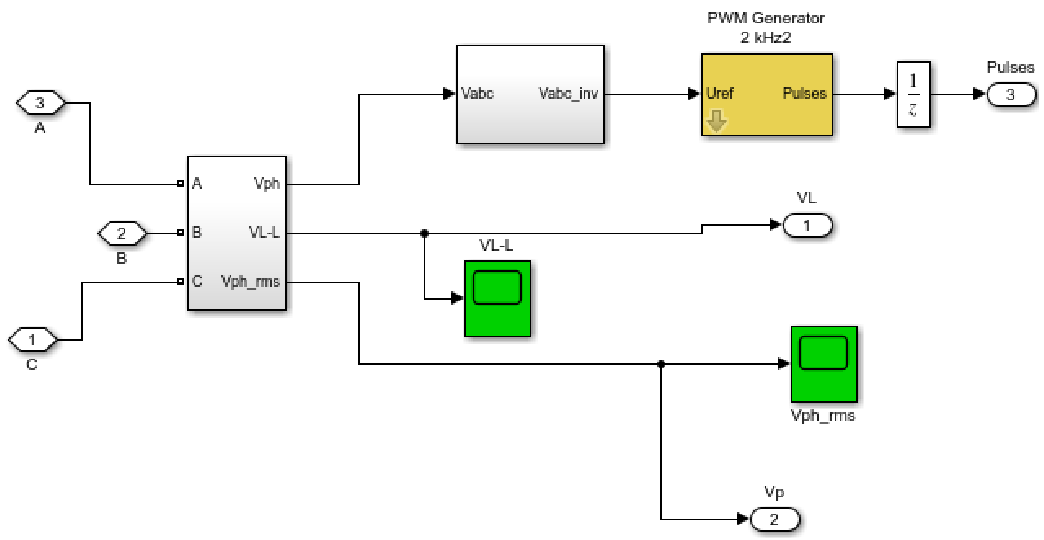



Figure 3.18: Inverter PWM control Simulink

The inverter contain LC filter to reduce the harmonics contain 2 mL inductance and capacitor 6 μF that shown in the Figure 3.19.

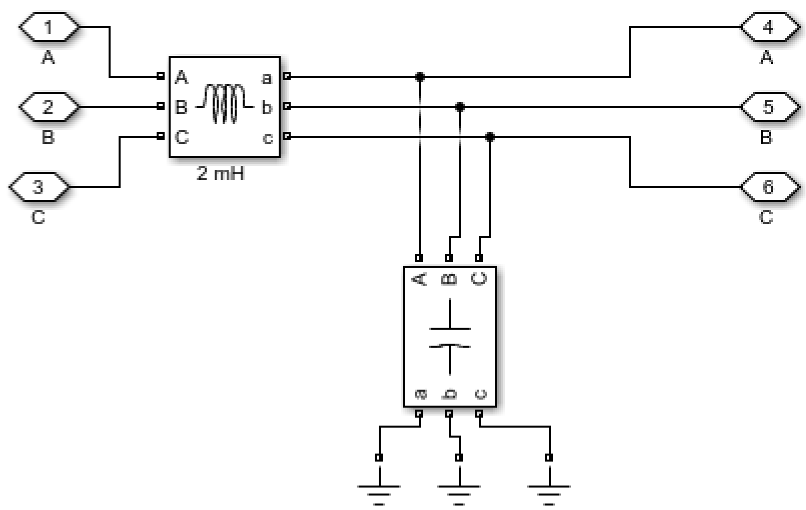



Figure 3.19: LC filter Simulink

### 3.3.4 Load

the system intended to use by five houses each house assume that it consume 30 KWh per day[7].the Figure 3.20 show the diagram of the Load.

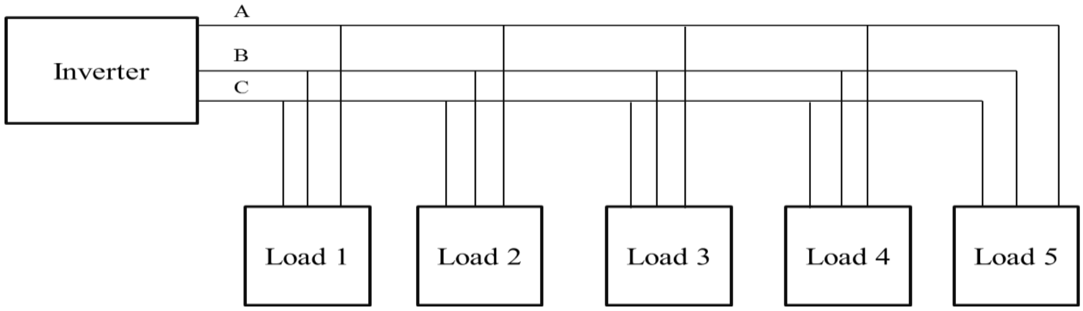



Figure 3.20: Loads diagram

The loads working in 385 V as rated voltage[57]. The simulation using three RLC parallel load that available in Matlab library. The Figure 3.21 shows the Loads simulation

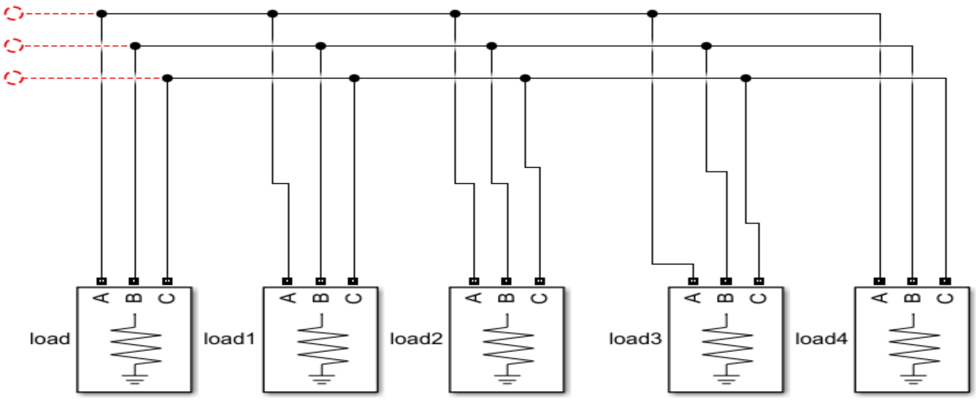



Figure 3.21: Loads in Matlab/Simulink

## 3.4 The Wind Energy Power System

The wind system is a system that convert the kinetic energy of wind into useful electrical energy[30].The system contain of different parts to generate AC power ,invert it into AC, battery Bank, control and loads that used the generated power. The system designed to produce maximum AC power 14KW. The Figure 3.22 shows the parts of the wind power system.

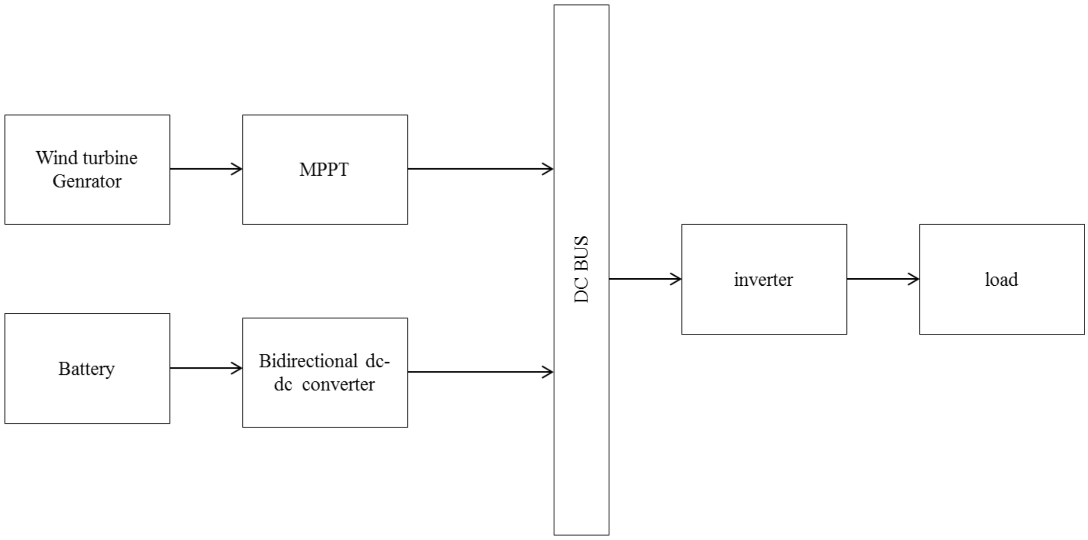



Figure3.22: The block diagram of wind system

The simulation of the system had been done by using Matlab 2017b Simulink software by depending of the available models in the Matlab libraries. The Figure 3.23 shows the wind power system Simulink

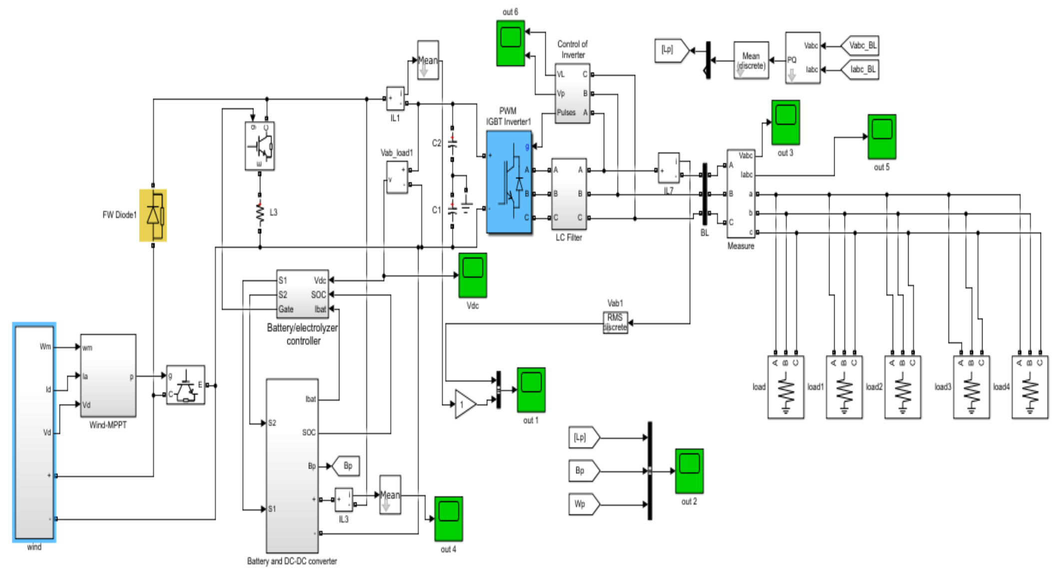



Figure 3.23: The wind power system  in Simulink

### 3.4.1 Wind Turbine Generator

Wind turbine generator is the unit that responsible for generation DC electrical from by converting the kinetic energy of the wind to useful electrical energy. This part of the system consists of different parts, wind turbine, Generator, MPPT and rectifier. That system use permanent magnet synchronous generator due to its high efficiency which is belong to that it have movable magnetic source inside itself. The Figure 3.24 show the block diagram of the wind turbine generator parts. The wind turbine generator Simulink shown in the Figure 3.25

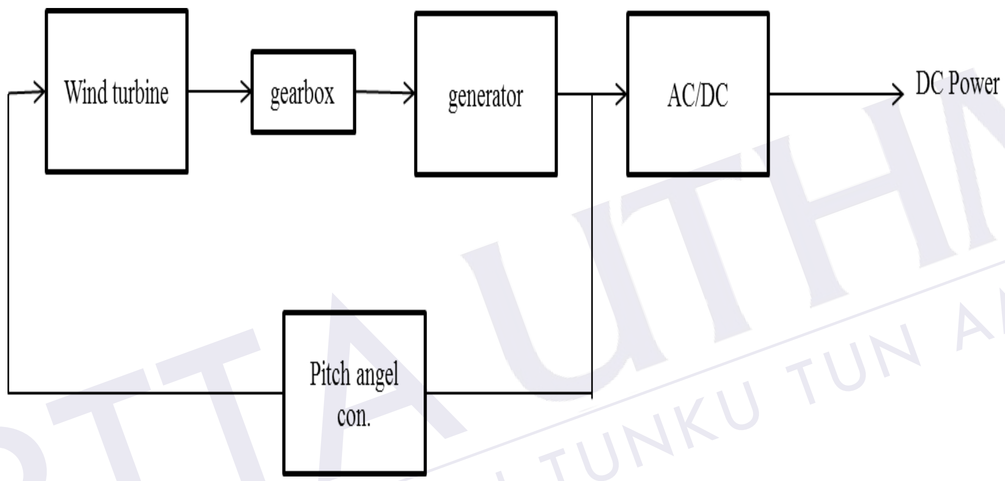



Figure 3.24: The block diagram of wind turbine generator

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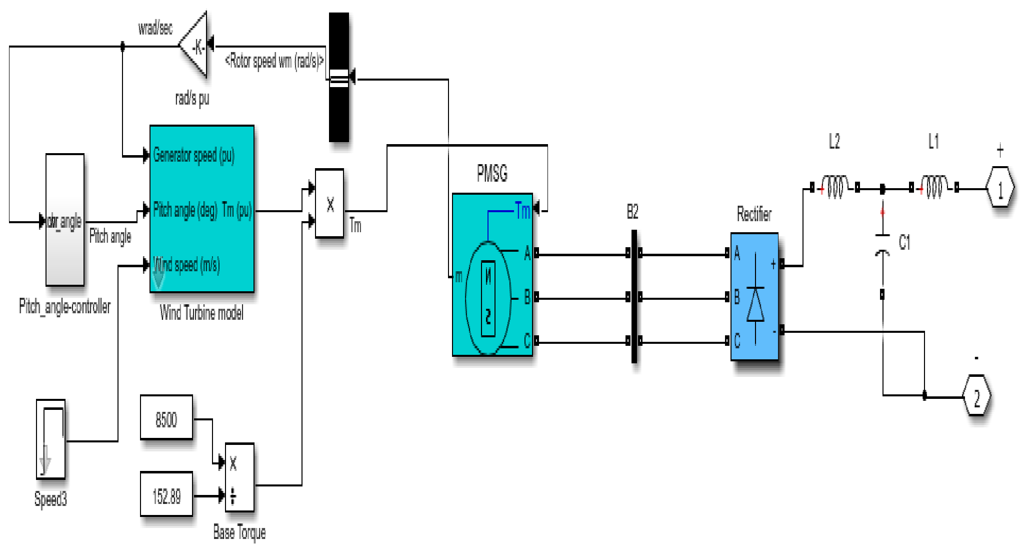



Figure 3.25: The wind turbine generator Simulink

### 3.4.1.1 Wind turbine

Wind turbine is that mechanical part of the system which is convert the kinetic energy in wind into rotating energy transferred to the generator[30]. The mechanical power of the turbine can obtain by equation 3.2.

$$P = \frac{1}{2}\rho A C_{\rho} v^{3} \tag{3.2}$$

P is the mechanical o/p power of the turbine

ρ is the air density

v is the wind speed

$C_p$ is the power coefficient

The parameter that depending the modeling of the turbine mention in the Table 3.2

Table 3.2: Turbine parameter [58]

| Parameter | Value |
|---|---|
| Nominal mechanical output power | 8.5e3 W |
| Base power of electrical generator | 8.5e3/0.9 VA |
| Base wind speed | 12 m/s |
| Maximum power at base wind speed | 0.8 p.u. |
| Base rational speed | 1 p.u. |

The simulation depending on the model simulation that available in simscape Matlab library that shown in Figure 3.26

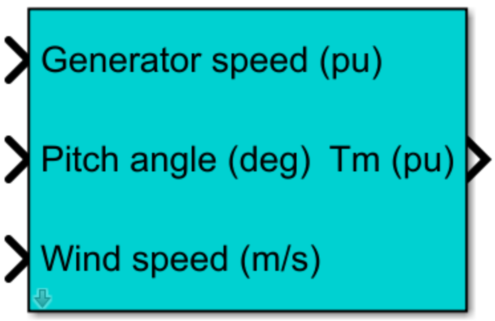



Figure 3.26: Wind turbine simulation model

Nevertheless the wind turbine pitch angel controller to avoid the generator speed goes too high or goes too slow. The pitch angel controller using PI technique [58] which is using the turbine characteristic and compare between the generator speed and its base speed , when β=0 and λ=6.325 $C_p$ is maximum . Wind turbine characteristic is shown in the Figure 3.27 when β=0. The simulation of pitch angel controller shown in the Figure 3.28.

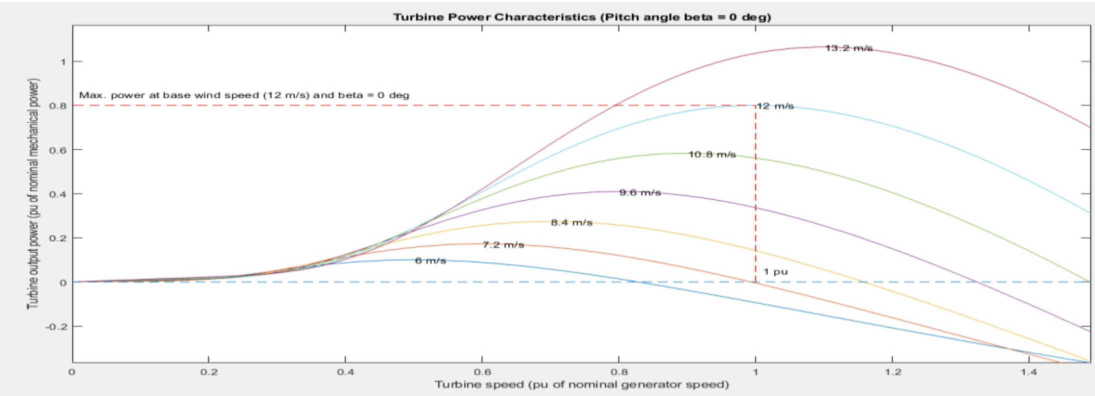



Figure 3.27: The turbine characteristic at β=0

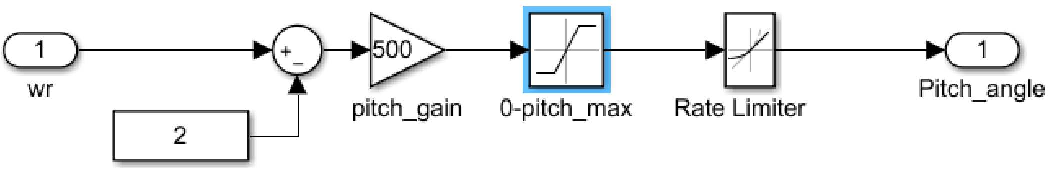



Figure 3.28: The pitch angel controller Simulink

### 3.4.1.2 Generator

Generator is the part that responsible to convert the rotating mechanical energy that produce by wind turbine to electrical energy [30]. The permanent magnet synchronous generator used in the work , due to its high stability and the fact that is PMSG doesn't need to use gearbox in case of using high pair poles but in this work gearbox has used due to economic reason . the modeling of the PMSG is done by using below equations [58].

$$\frac{d}{dt} i_d = \frac{1}{L_{ds} - L_{1s}} \left(-R_s i_d + w_e (L_{qs} + L_{1s}) i_q + u_d\right) \tag{3.3}$$

$$\frac{d}{dt} i_q = \frac{1}{L_{qs} + L_{1s}} (-R_s i_q - w_e [(L_{qs} + L_{1s}) i_d + \varphi_f] + u_d \tag{3.4}$$

$R_s$ is stator resistance

$L_{ds}$ and $L_{qs}$ are direct and quadrature axis inductances of generator

$L_{ls}$ are leakage inductances

$\varphi_f$ is the permanent magnetic flux

$\omega_e$ is the electrical rotating speed of the generator

$I_d$ is d axis stator current

$I_q$ is q axis stator current

$U_d$ is direct axis stator voltage

$U_q$ is quadrature axis stator voltage.

P is the number of pole pair of the generator.

On the other hand the electromagnetic torque of the generator have calculated by using the following equation

$$\tau_e = 1.5(L_{ds} - L_{qs})i_d i_q + i_d \psi_f \quad (3.5)$$

The parameter that used mention in Table 3.3

Table 3.3 : PMSG parameter[58]

| Parameter | Value |
|---|---|
| Rated speed | 153 rad/s |
| Number of pole | 10 |
| Rated current | 12 A |
| Stator resistance | 0.425 |
| Stator inductance | 0.000835 H |
| Rated torque | 49 Nm |
| Magnetic flux | 0.433wb |
| Rated power | 6 KW |

The simulation part of PMSG has done depending on the available model of PMSG in the simscape library of Matlab 2017b. The Figure 3.29 the PMSG model

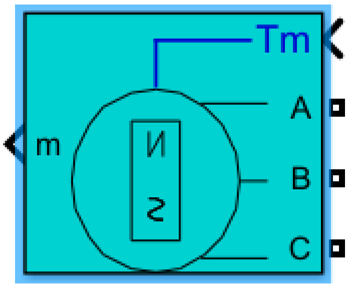



Figure 3.29: Permanent magnet synchronous generator Simulink model

### 3.4.2 Rectifier

Rectifier is the part that responsible to convert the AC voltage power that generated by the PMSG to DC voltage[30]. The Figure 2.10 showed the circuit of the rectifier in Chapter 2.

The system contains diode three phase full wave rectifying. Nevertheless the rectifying circuit contain LCL filter to reduce the number of harmonics that injected by the rectifier circuit[59]. The Figure 3.30 shows the circuit of the LCL filter. The parameters of the rectifier is mention in Table 3.4

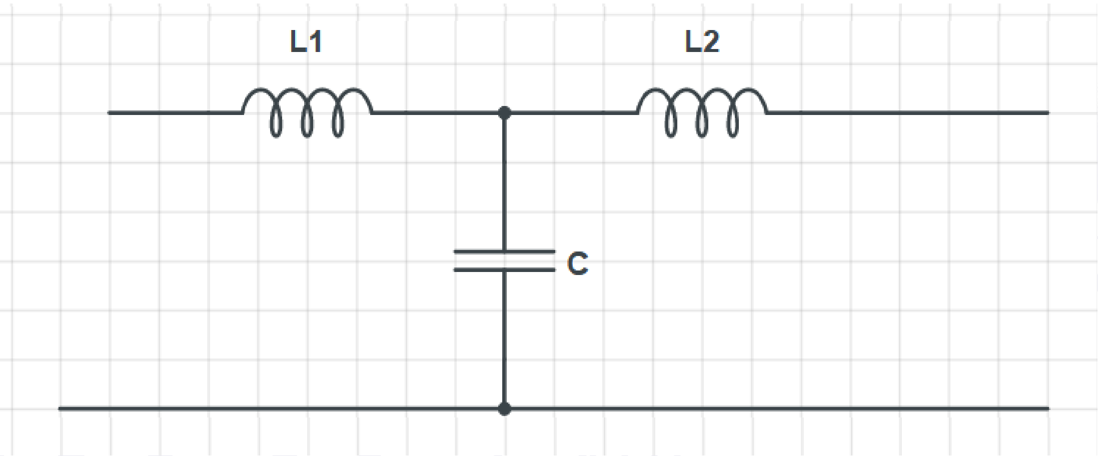



Figure 3.30: The LCL filter circuit

Table 3.4: The rectifier parameter[59]

| parameter | Value |
|---|---|
| Forward voltage | 0.8 V |
| Snubber resistance | 100 Ω |
| Snubber capacitance | 0.1e-6 F |
| $R_{on}$ | 1e-3 Ω |
| $L_{on}$ | 0 H |
| Filter $L_1$ , $L_2$ | 2e-3 H |
| Filter capacitance | 1000e-6 F |

The simulation using the universal bridge three arm referred to the rectifier the model available in Matlab libraries, The Figure 3.31 show the Simulink of the rectifier converter with filter

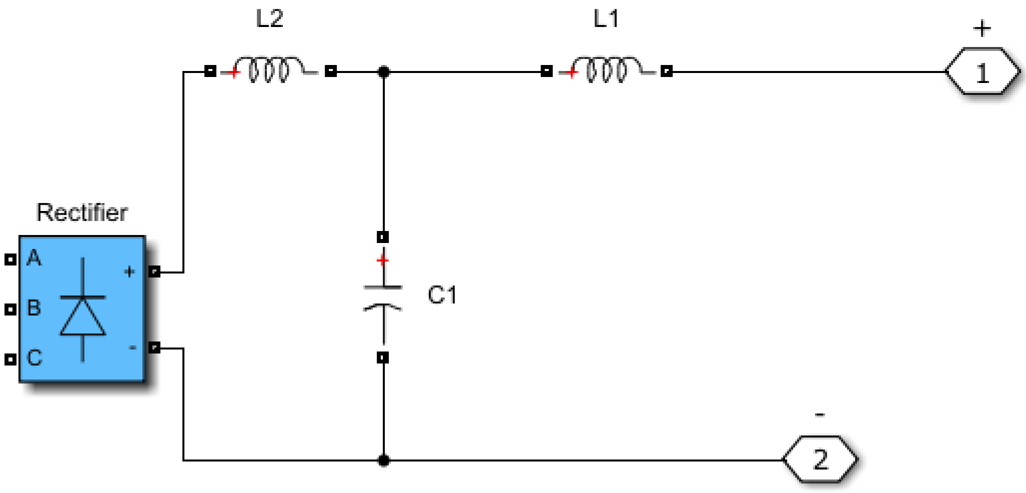



Figure 3.31: Rectifier converter with LCL filter Simulink

### 3.4.3 Wind generator maximum power point tracking

Maximum power point tracking is the part that responsible to control and maximize the power that generated by the PMSG. The Current control for small wind turbine MPPT technique [60] that used to small turbine below 50KW. The Figure below the block diagram of the control by using current control.

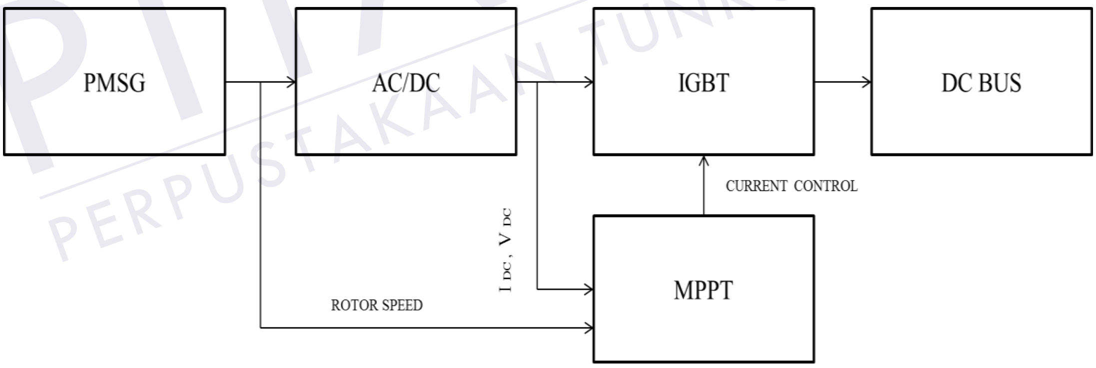



Figure 3.32: MPPT block diagram

The MPPT current technique calculates the rotor speed, $I_{DC}$ and $V_{DC}$. The system calculate the reference torque by the rotor speed, the following step is to calculate the reference current depending on the DC voltage, rotor speed and reference torque. The last step is to compare the reference current with present current. Then the output being an input to IGBT to control the output voltage of wind on 640v to keep the stability of the system and avoid disturbance the resulted from two different source with different voltage in common DC bus. The Figure 3.31 show the flow chart of the MPPT work

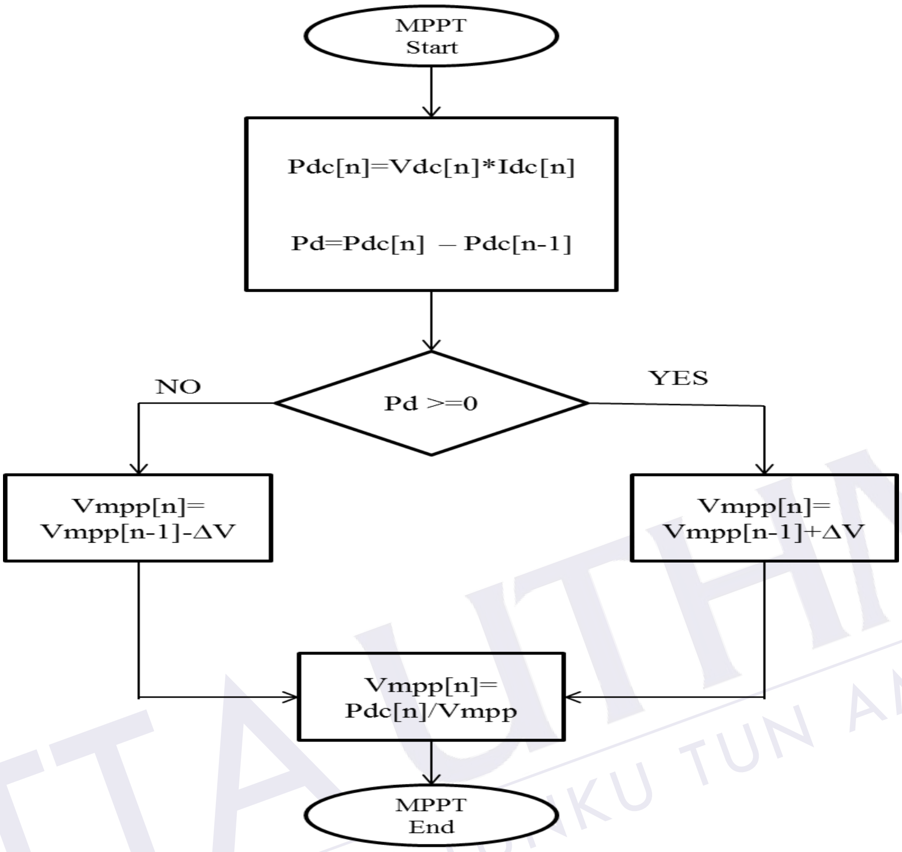



Figure 3.33: Flow chart of MPPT

The Simulink of wind turbine MPPT has been done by using mathematical equations to get finally the reference current to compare to the wind generated current. The Figure 3.34 shows the MPPT in Matlab Simulink.

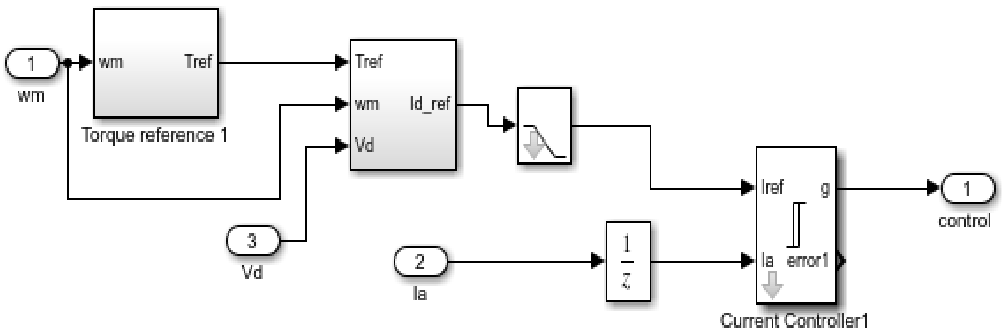



Figure 3.34: The wind turbine MPPT Simulink

### 3.4.4 Battery system and the inverter system

The battery system and inverter are the parts of the system that responsible to save energy to fed the system with it in case of absence of the renewable energy and invert it to AC voltage to use by householders for more details the system discuss in sections 3.3.2 and 3.3.3 in Chapter III.

### 3.4.5 Load

The system intended to use by five houses each house assume that it consume 30 KWh per day more details mention in section 3.3.4

## 3.5 Hybridization of PV-Wind systems

Hybridization is the process of combining two or more of power sources. Hybrid PV wind energy power system is that system that convert the sun irradiance and wind speed energy to electrical energy simultaneously or asynchronously. The most important feature of the hybrid system the fact that is each system support the weakness point of the other, Example the availability of the renewable source and the benefit of the hybrid system the fact that the system don't depend on one renewable source due to its unexpected nature. The system part shown in the Figure 3.35.

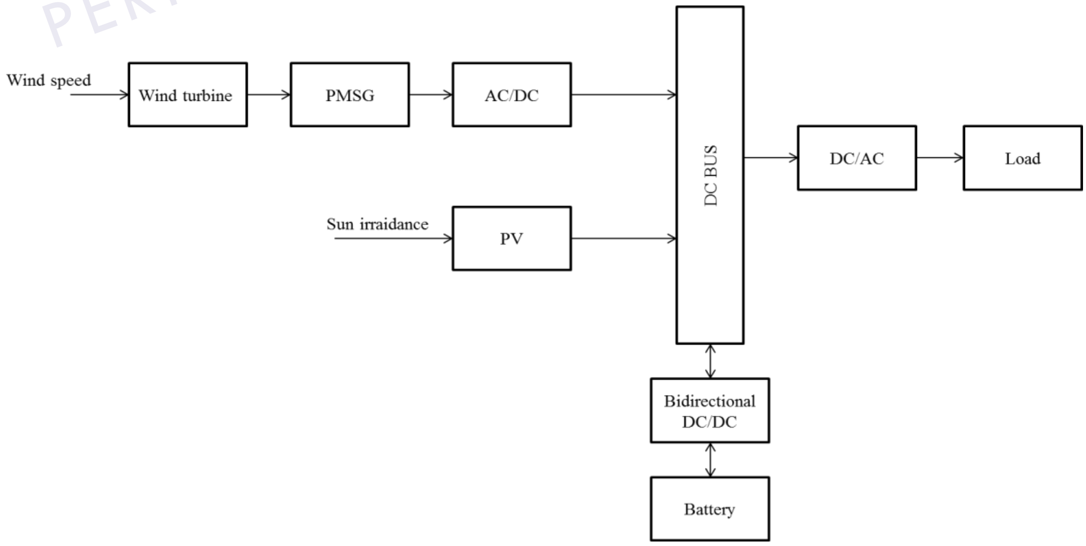



Figure 3.35: Block diagram of hybrid PV-wind power system

Combine of the two systems by using DC link. The combine of the two systems have done under DC voltage 640 V. The power system design to support five householders each one assume to consume 30KW per day. The Figure 3.36 show the Simulink of the hybrid PV wind renewable energy power system.

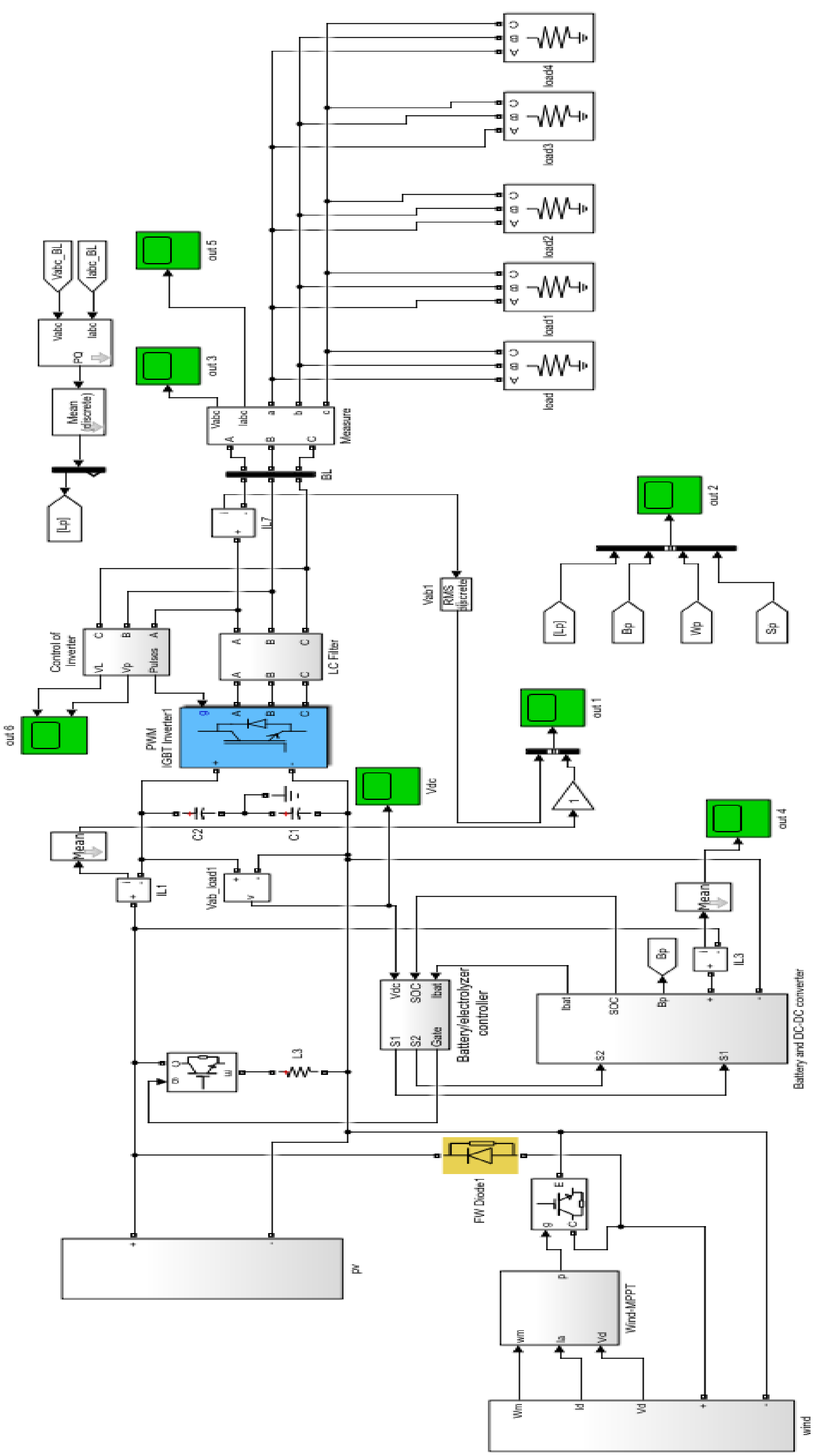


Figure 3.36: The hybrid PV wind renewable energy power system Simulink

# CHAPTER 4

## RESULTS AND DISCUSSION

### 4.1 Introduction

Chapter four includes the systems results of the PV, the Wind and the hybrid PV-Wind. Moreover this chapter also included the analyzing of the results. The results that include in this chapter have obtained from Matlab Simulink software version 2017b.

### 4.2 Input data

The problem state included the motivation that is Iraq suffering of high shortage of power generated depending on that motivation the set of input data base Iraq as case study.

The systems Simulink tested for a day on January which present winter season which have the lowest day hours and the lowest average of wind speed during the year. The place of measurement the sun irradiance power and wind speed is in Baghdad which is city in middle of Iraq. The system tested under the worst case to test the withstanding of systems. The Table 4.1 on demonstrate the data base that have used in work

Table 4.1 : Input data (sun irradiance and wind speed ) that used in work [51]

| Time | Sun irradiance ($w/m^2$) | Wind speed (m/s) |
|---|---|---|
| 12:00 AM | 0 | 0.06 |
| 1:00 AM | 0 | 0.1 |
| 2:00 AM | 0 | 0.3 |
| 3:00 AM | 0 | 0.5 |

| | | |
|---|---|---|
| 4:00 AM | 0 | 1.1 |
| 5:00 AM | 0 | 1.3 |
| 6:00 AM | 0 | 1.1 |
| 7:00 AM | 48.6 | 0.06 |
| 8:00 AM | 180.4 | 0.1 |
| 9:00 AM | 324.4 | 0.3 |
| 10:00 AM | 441.6 | 0.5 |
| 11:00 AM | 510.2 | 1.1 |
| 12:00 PM | 530 | 1 |
| 1:00 PM | 473.4 | 1.1 |
| 2:00 PM | 378.8 | 1.3 |
| 3:00 PM | 241.2 | 1.1 |
| 4:00 PM | 100.4 | 0.7 |
| 5:00 PM | 10.4 | 0.1 |
| 6:00 PM | 0 | 1.1 |
| 7:00 PM | 0 | 1.3 |
| 8:00 PM | 0 | 1.1 |
| 9:00 PM | 0 | 0.7 |
| 10:00 PM | 0 | 0.1 |
| 11:00 PM | 0 | 0.1 |

The oscillation of the wind speed and sun irradiance from Matlab shown in Figure 4.1 and 4.2. The waveform presented in 12 simulation time unit each one time unit present two hours. In sun irradiance can noticed that that the sun transfer power can used by PV system only during the middle of the day and the rest of day during the dark the power transferred to earth is zero. On the other hand the wind turbine can operated all the day.

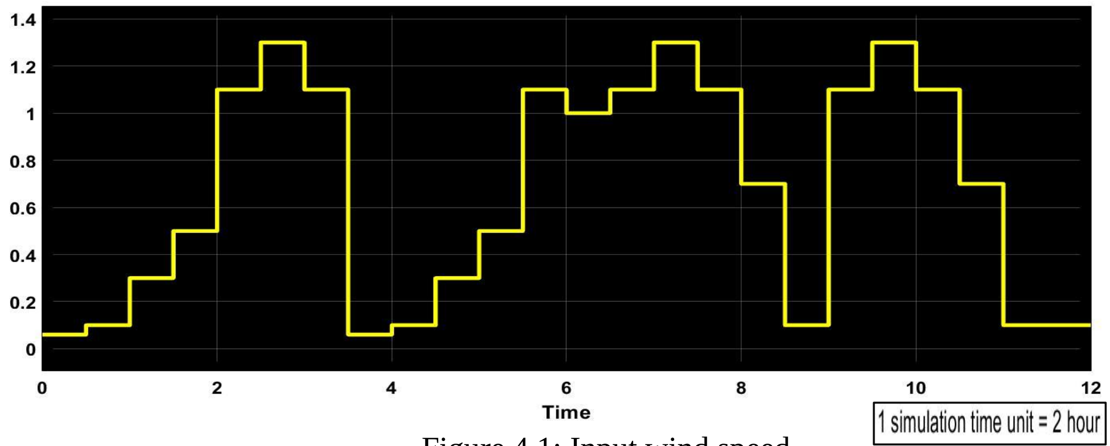



Figure 4.1: Input wind speed

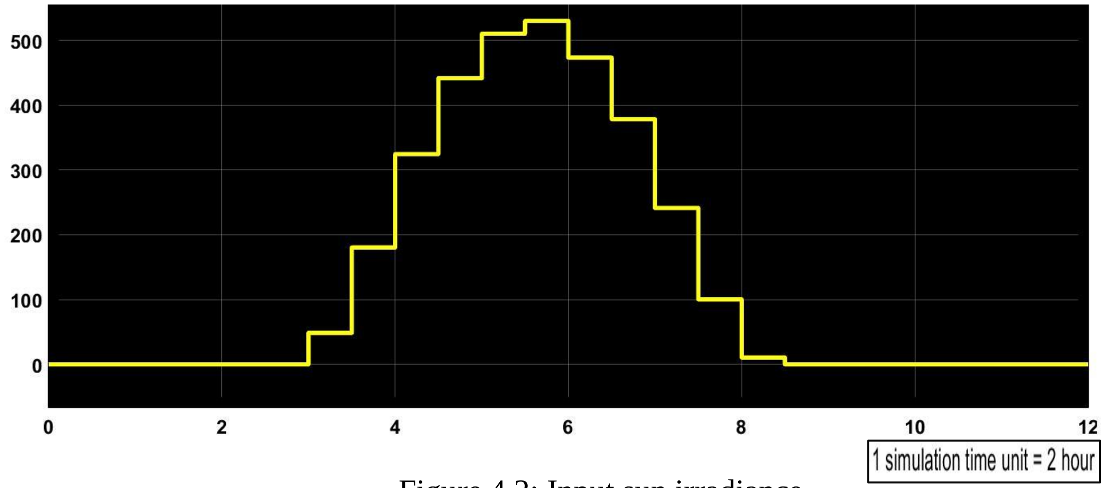



Figure 4.2: Input sun irradiance

## 4.3 PV system

PV module system that has explained in Section 3.3 in Chapter III and shown in Figure 3.3. This section contains the results of the PV system. The PV converts the sun irradiance into electrical energy. The waveform presented in 12 pulses each one pulse present two hours in real time system . The Figures 4.3, 4.4 and 4.5 show the output of the current, voltage and power of one panel respectively. Based on the Figures the current and the power change with vary of the sun irradiance during the day. On the other hand the voltage waveform approximately constant when PV generated an electricity.

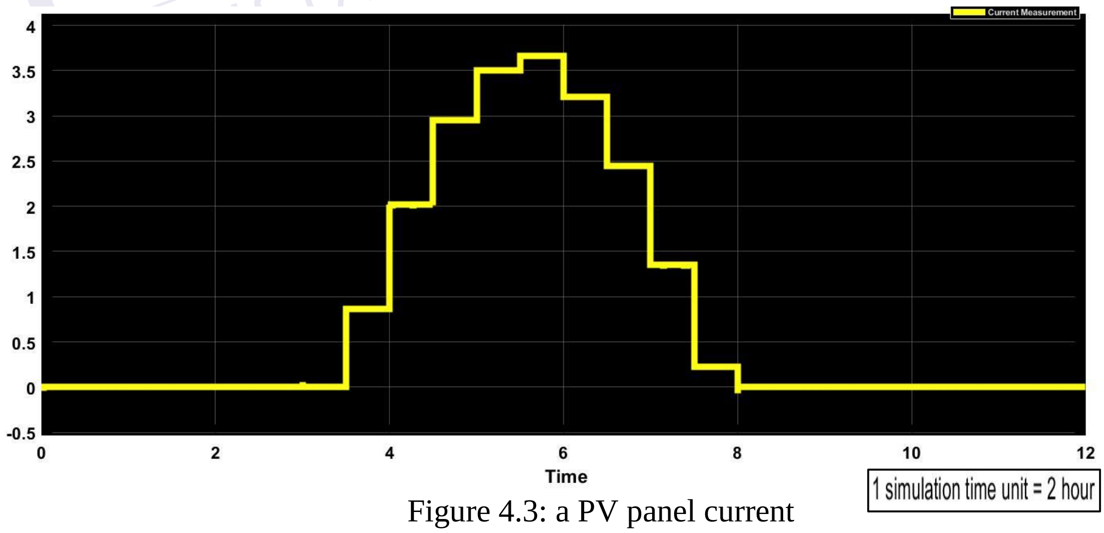



Figure 4.3: a PV panel current

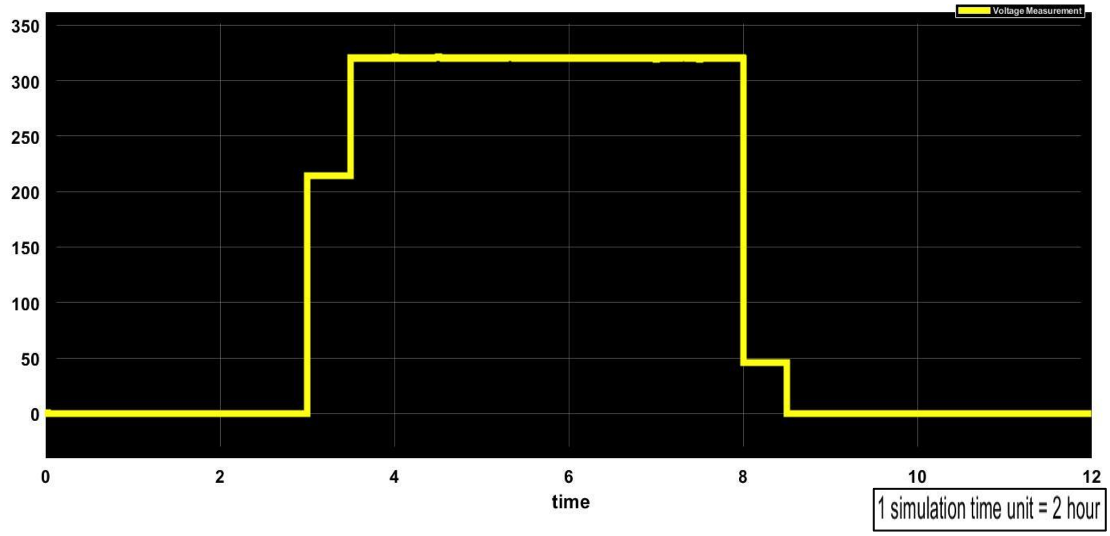



Figure 4.4: a PV panel voltage

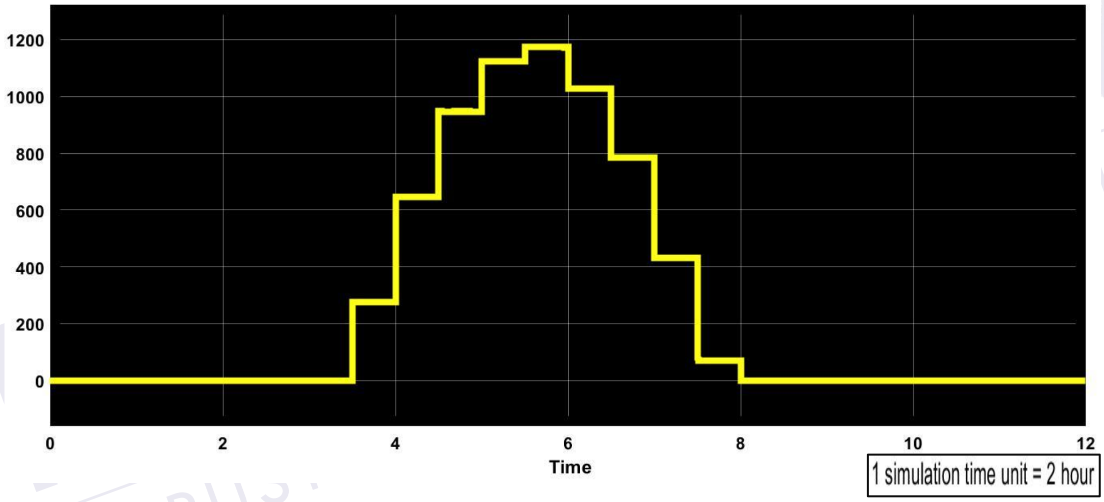



Figure 4.5: a PV panel power

The PV consist of four panels connected in parallel/series technique that explain in Section 3.3.1 in Chapter III to increase the current and voltage of overall system. The Figures 4.6, 4.7 and 4.8 show the total current, voltage and power of PV. Based on the result the current and voltage increase and the power increase four times. As mention in chapter III the PV array contain of four panels. The fact that is the connection of PV in parallel increase the voltage and in series increases the current.

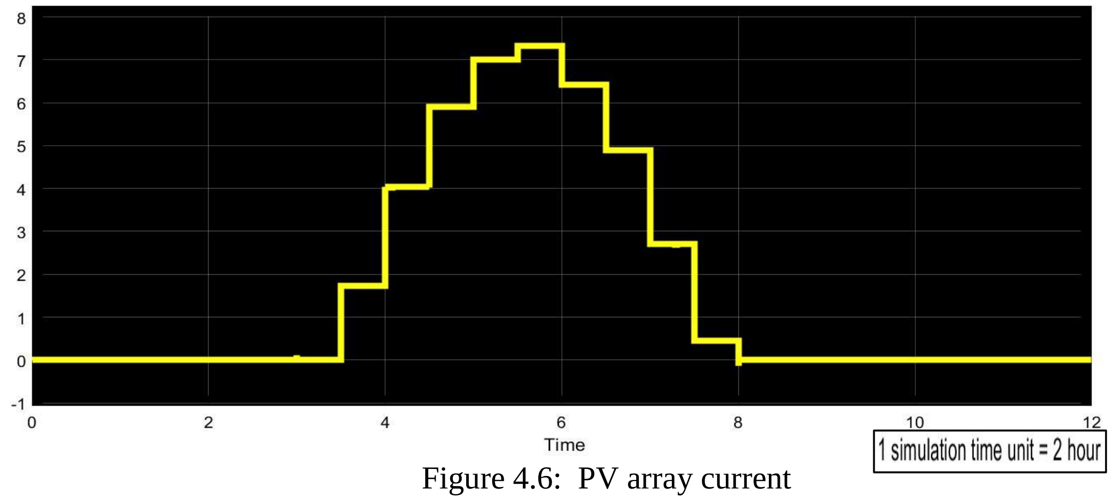



Figure 4.6: PV array current

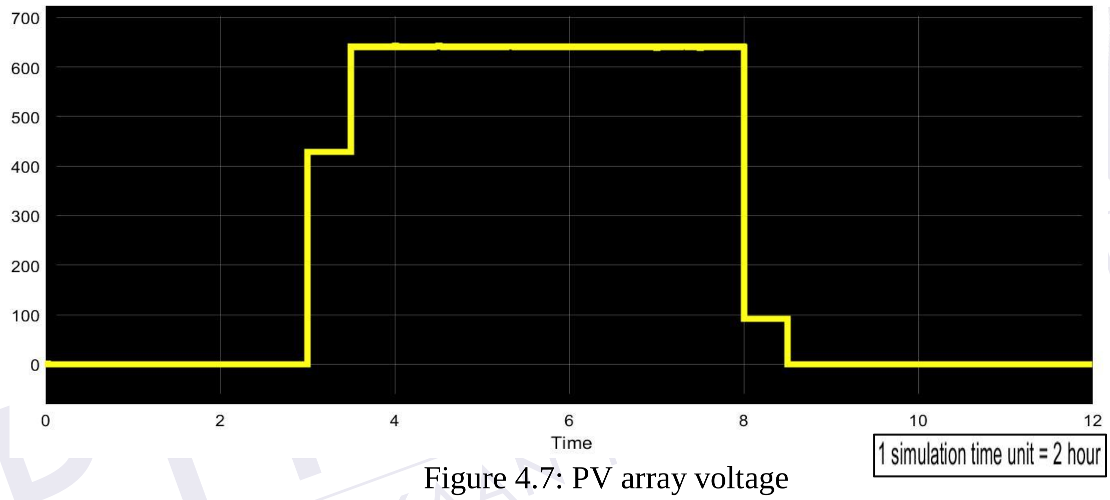



Figure 4.7: PV array voltage

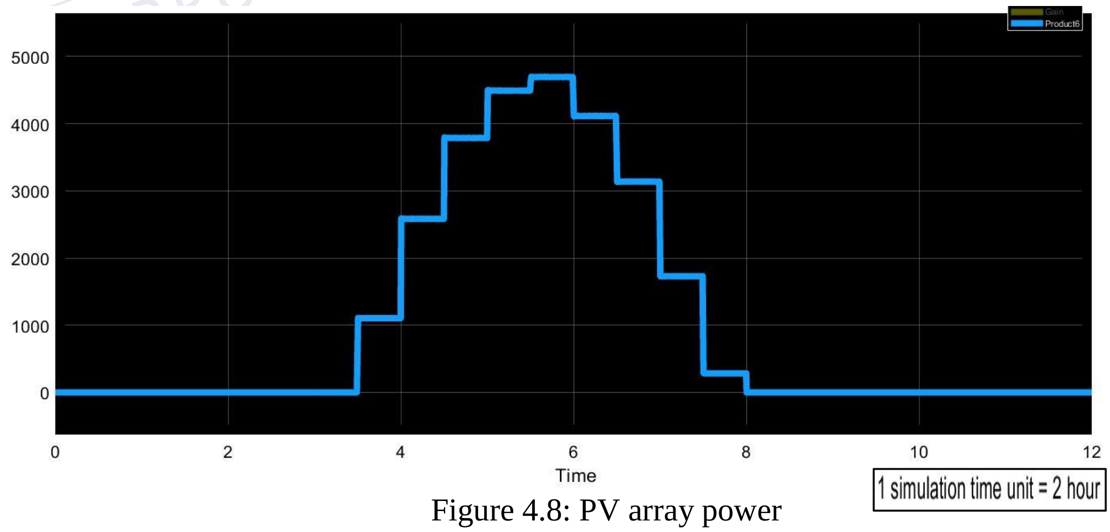



Figure 4.8: PV array power

The system contains battery bank of capacity 6.5 Ah. The battery use to charge in case generated power higher than demand power and fed load in case generated power less than the demand power. The Figure 4.9 shows the output current of battery. Based on figures  the Figure the current of battery decrees in the middle of day, due to sun rise, and as a result the battery fed  the load with the PV, but in both cases the battery fed load during the day due to the PV doesn't generated enough power to fully fed the demand power, The Figure 4.10 and 4.11 show the output power of battery and state of charge respectively. The figures show the battery power decrease in the middle of the day during PV generated power but it's never charged. So,  Then the battery will off when it reaches state of charge below 20%. As show in figure that the state of charge decreases from 60 to 59 during one day, Due to the fact that battery fed the loads during all the day. The Figure 4.12 shows the battery voltage. As shown in the figure  the battery voltage which is operate in voltage of 320 V to can charge and fed depending on the direction of the DC/DC bidirectional converter that has demonstrated in chapter III.

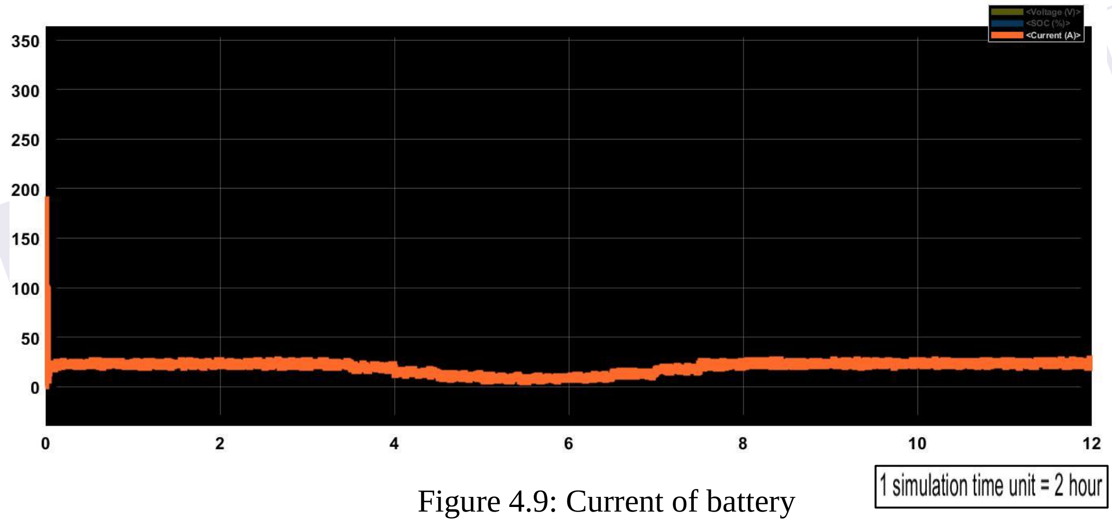



Figure 4.9: Current of battery

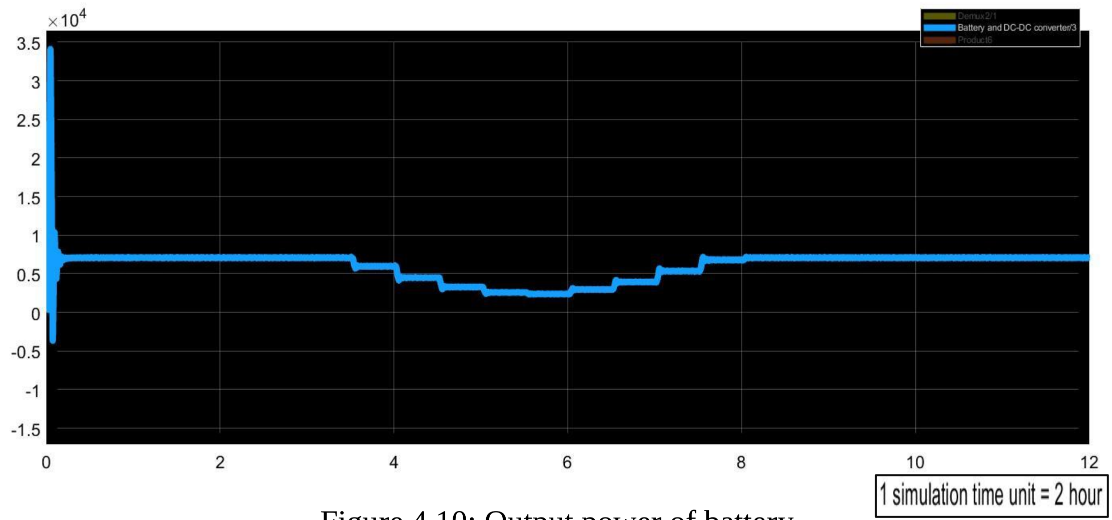



Figure 4.10: Output power of battery

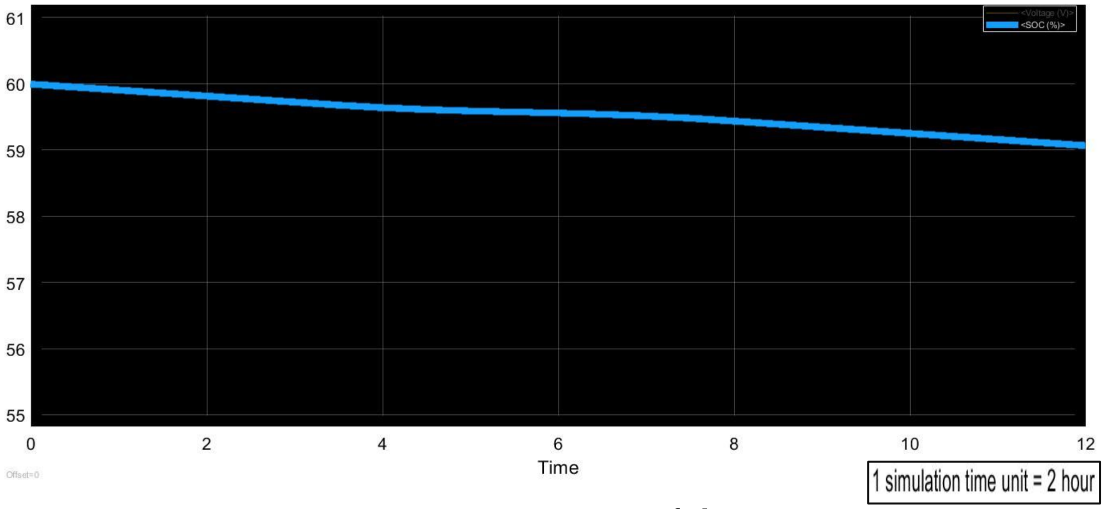



Figure 4.11: Battery sate of charge

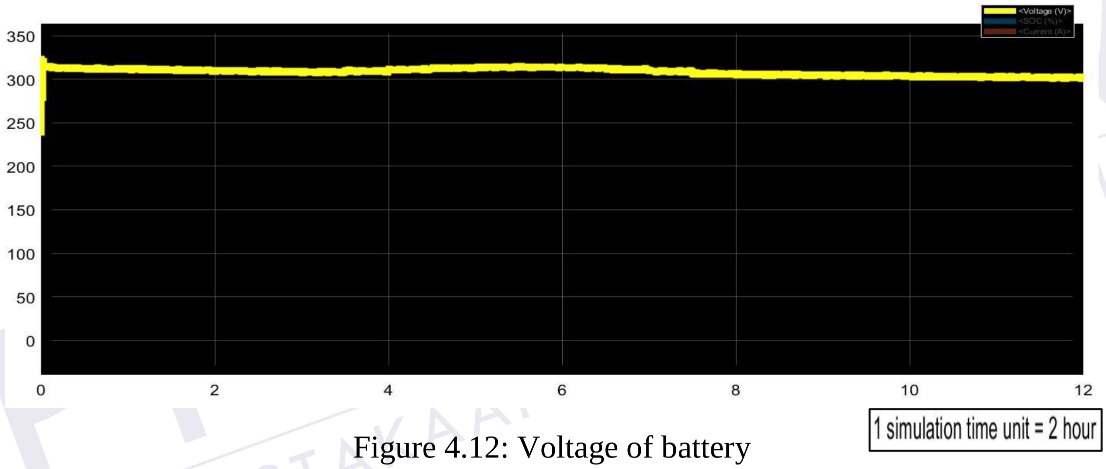



Figure 4.12: Voltage of battery

The control of the battery charge controls it by control the direct of the bidirectional DC/DC converter by trigged the IGBT. The charge control depending PI technique as demonstrated in Chapter III. The Figure 4.13 show the reference current that output of PI controller, the output of PI at start was standard high to reach the demand power when PV generate no power due to absent of the sun irradiance. In the middle of the day the PI output increase due the PV generates power because the sun rise and the transfer power that give solar the ability to generate power and as results the battery feeding power decrease. At the end of the day the output PI output increase to feeding more power from the battery. There is two output of the controller one off and the other on to trigger the bidirectional working as buck or boost depending on the controller output as shown in Figure 4.14. The output of controller has been smoothing to be understandable which one of the system drawback that the controller is not stable. As shown in the figure the bidirectional DC/DC converter working as boost during the day which is mean that PV doesn't reach the demand power during the day. The power that feeding to the load

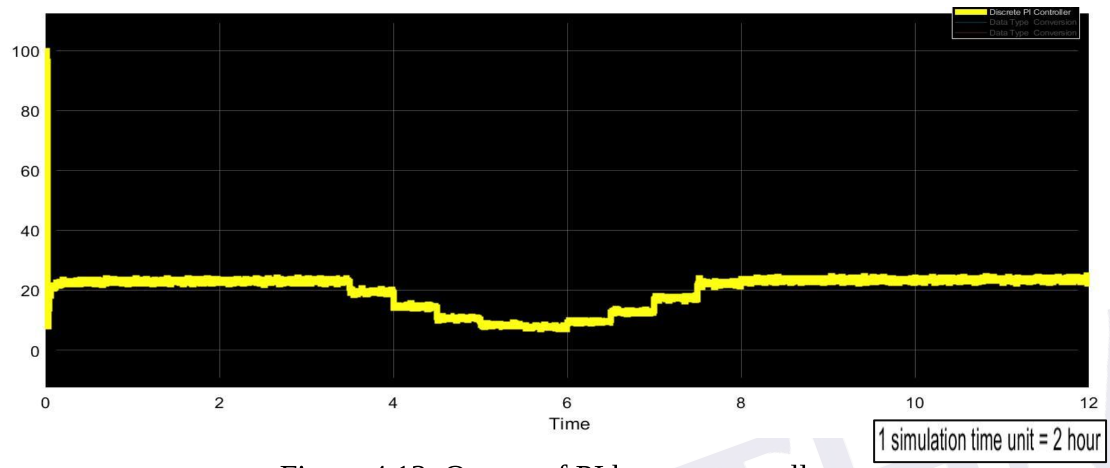



Figure 4.13: Output of PI battery controller

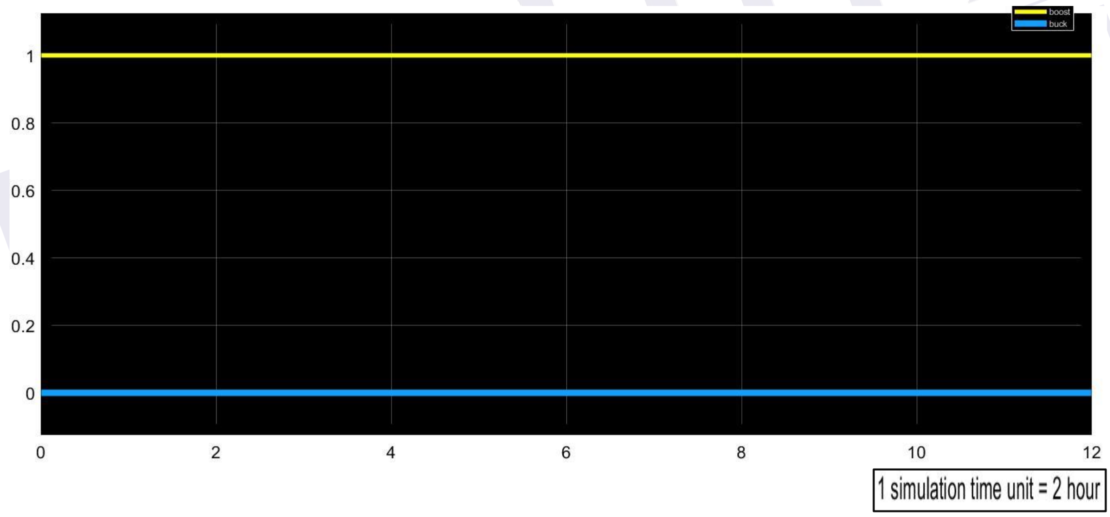



Figure 4.14: The battery controller output

The PV system operate in 640 $V_{dc}$. The Figure 4.15 shows the DC voltage of the PV system which is  stable and the voltage steady on 640 V. Moreover, the Figure 4.16 show the DC current . The figure shows that the current is stable is steady at 10 A. Which is mean that the load fed by the demand power with continuous power without distribution.

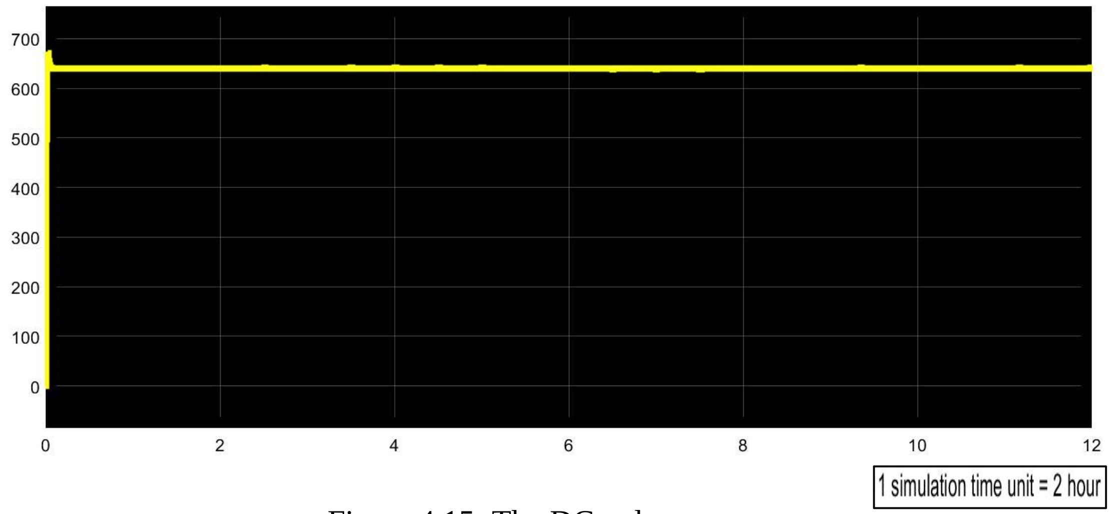



Figure 4.15: The DC voltage output

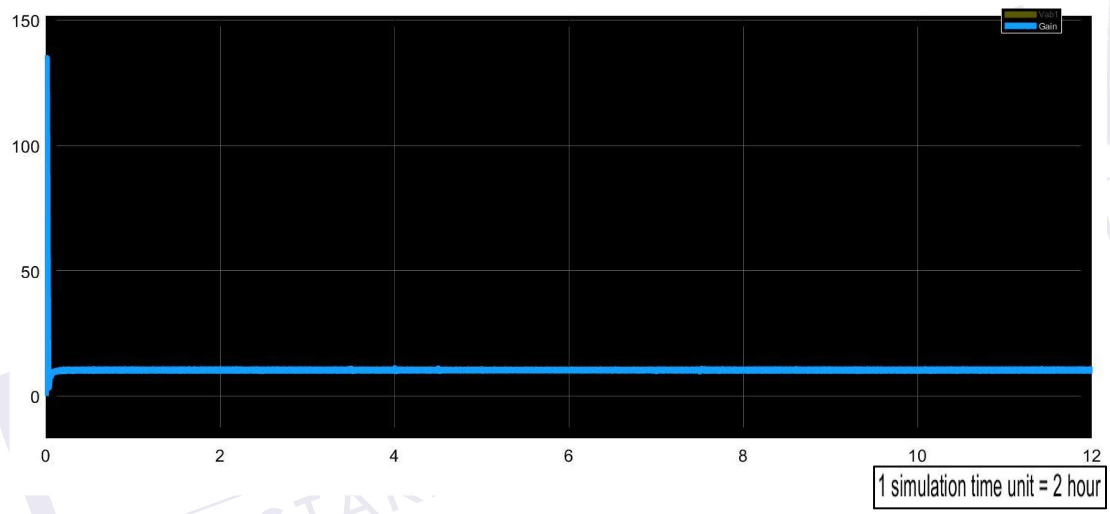



Figure 4.16: The DC current output

The last step to fed power into the load is inverting the power to AC voltage. The Figures 4.17 and 4.18 show the AC power parameters and presents the line to line voltage and AC rms voltage respectively, under Iraq system condition which is 680 V and 220 V respectively. The figure show that AC voltage line to line is pure since wave without distribution and the system work well to fed for householders. Moreover the load voltage and the current shown in Figures 4.19 and 4.20 respectively. The load voltage and the current are sin wave and no harmonics and very little distribution in voltage and current which is mean that PV system is stable. The distribution loads voltages and current is one of renewable drawback which is need to develop.

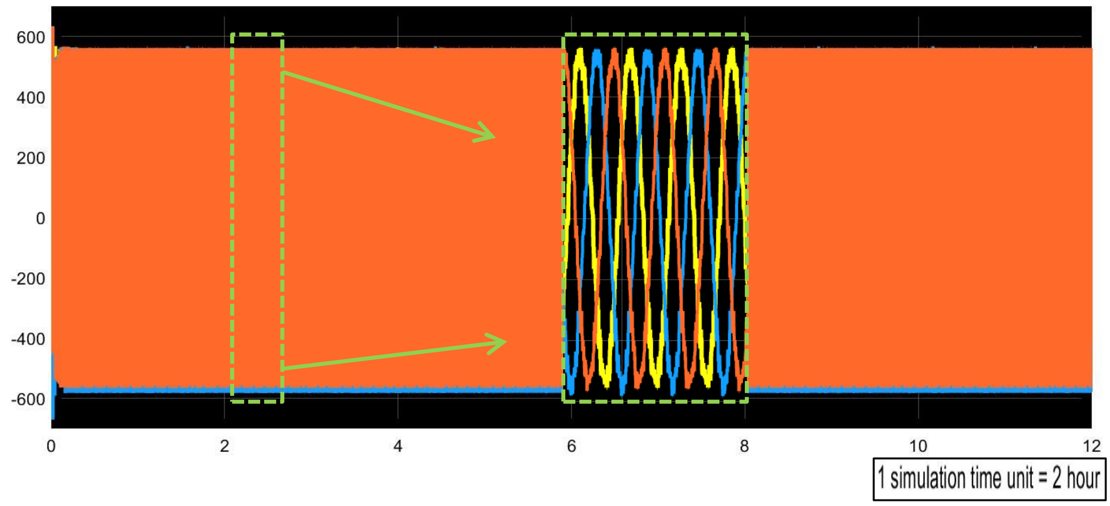



Figure 4.17: System line to line AC voltage

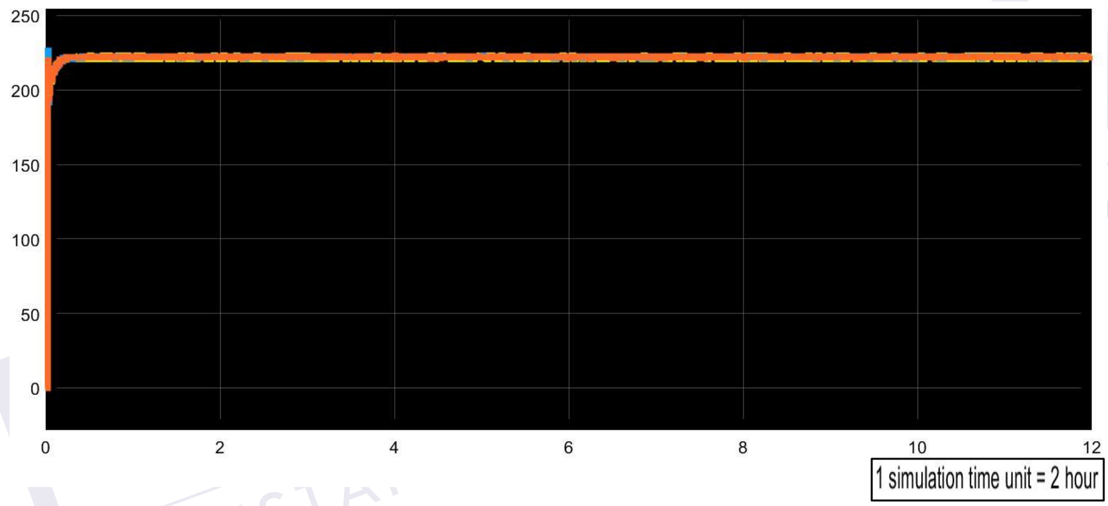



Figure 4.18: PV system RMS AC phase voltage

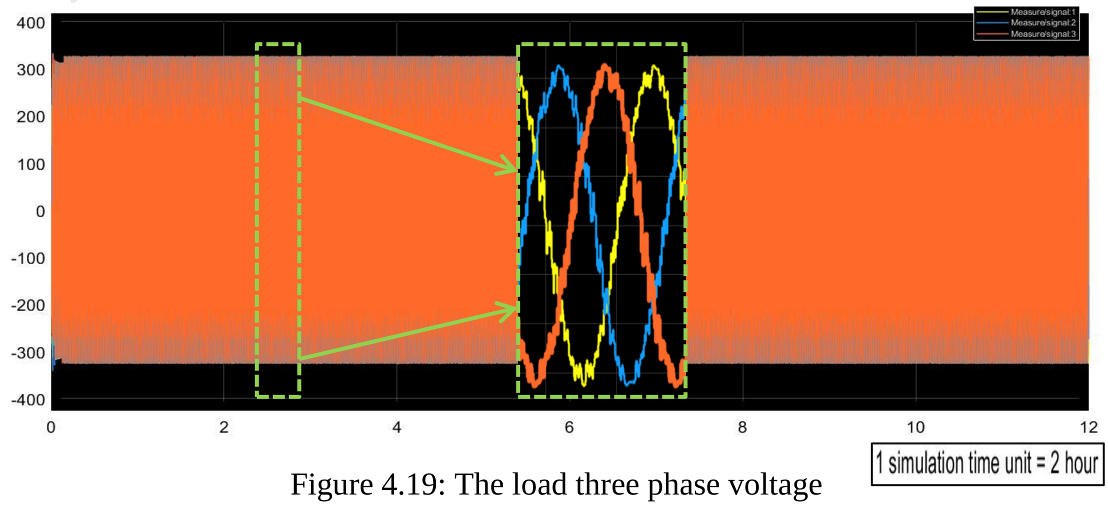



Figure 4.19: The load three phase voltage

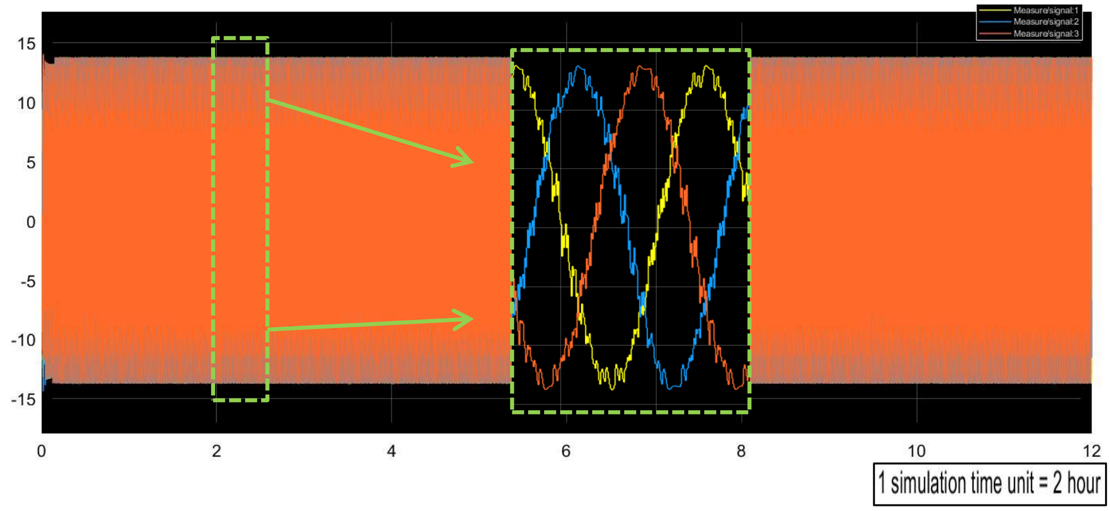



Figure 4.20: The load current

The Figure 4.21 shows the power of the PV, battery and load power demand. As shown in the figure the PV doesn't generated electricity only in day hours which 8 hours and the rest of the day battery fed the whole demand load. Moreover noticed that during the day hour's battery also fed a part of the demand load because that the PV doesn't generate enough power to feed the demand load.

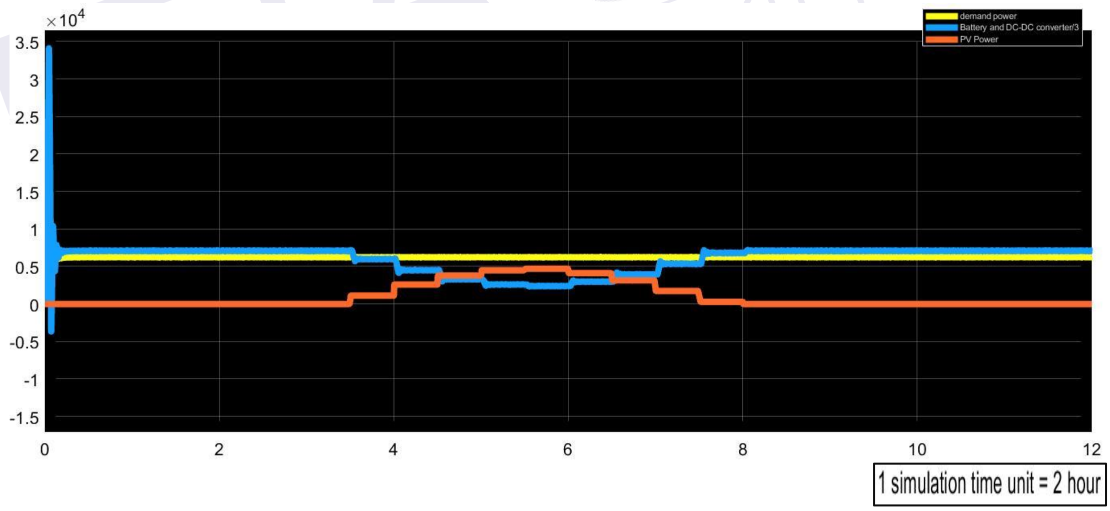



Figure 4.21: Overall PV system powers

## 4.4 Wind renewable energy power system

The wind system is a system that converts the wind speed to AC voltage power that as explain and modeled in section 3.4 in chapter III and the system shown in Figure 3.21. The Figures 4.22, 4.23 and 4.24 shows the PMSG generated AC voltage, current and power respectively. The figures show the difference between wind turbine and PV  Firstly, in wind turbine generate electricity during the day in other word there’s no daily time to stop generate like night in PV. Secondly, difference the fact that the effect of change in input doesn’t make noticed change in current and the power. Nevertheless the fact the wind turbine generate AC voltage power that’s mean that the system contain rectifier when PV doesn’t need to rectifier. The figures show that the wind turbine produce AC $V_{max}$ 1.5 KV  and current ac $I_{max}$ 12 A. The  AC power that produced by the Wind turbine is maximum 8 KW.

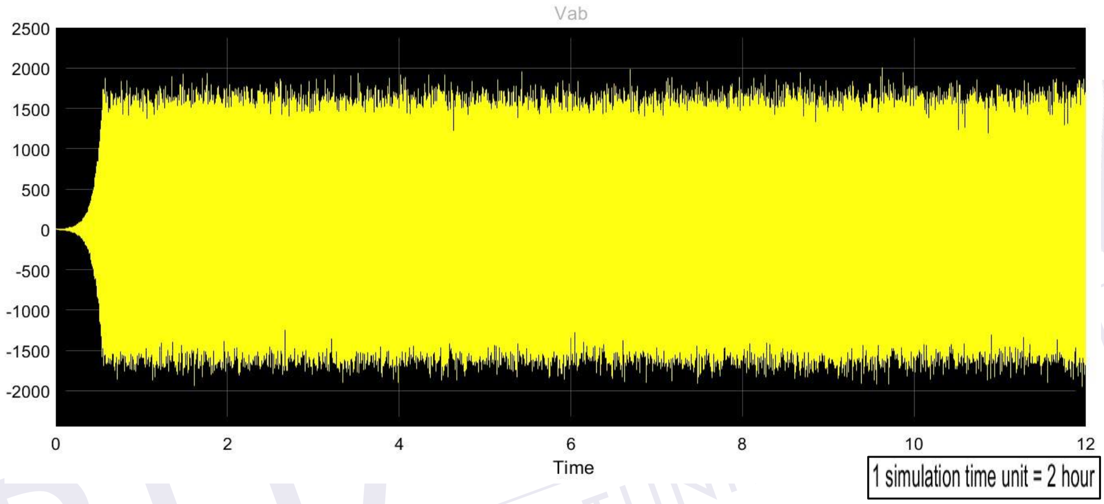



Figure 4.22: AC voltage  of PMSG generated

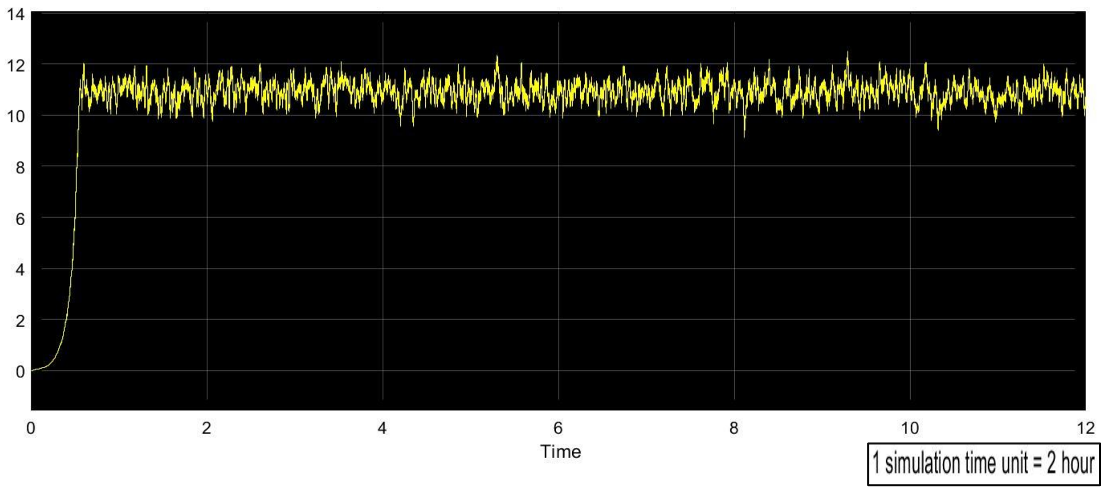



Figure 4.23: AC RMS current  of PMSG

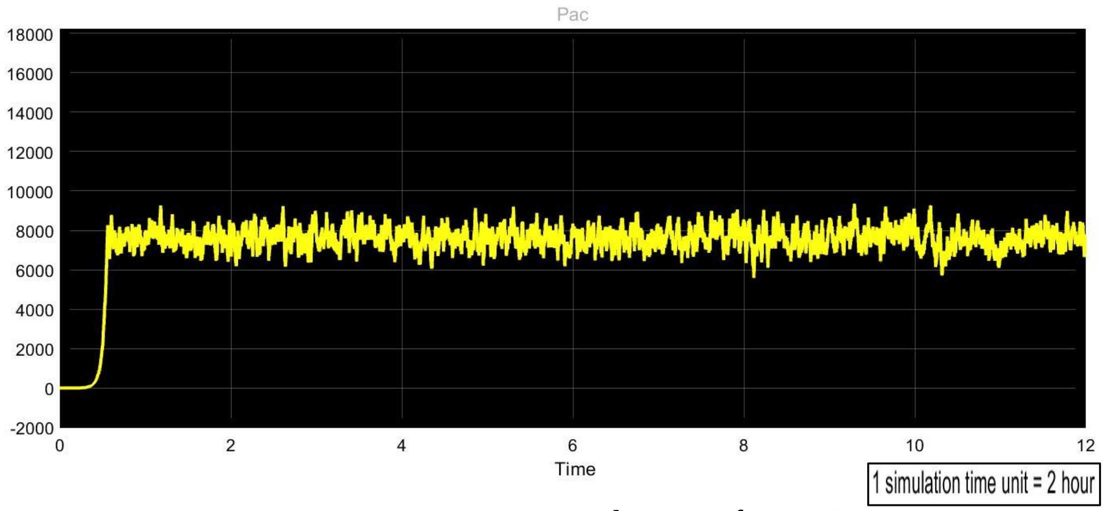



Figure 4.24: RMS generated power of PMSG

The system contain using of DC bus. The output of the wind turbine had converted to DC by using full wave rectifier. The Figures 4.25, 4.26 and 4.27 show the DC voltage, current and power respectively. It is noticed that that the output of the rectifying is less the AC generated power because of the rectifier. The DC voltage operate in system DC voltage which is 640 V. The DC current is 7 A. The DC power is 5 KW.

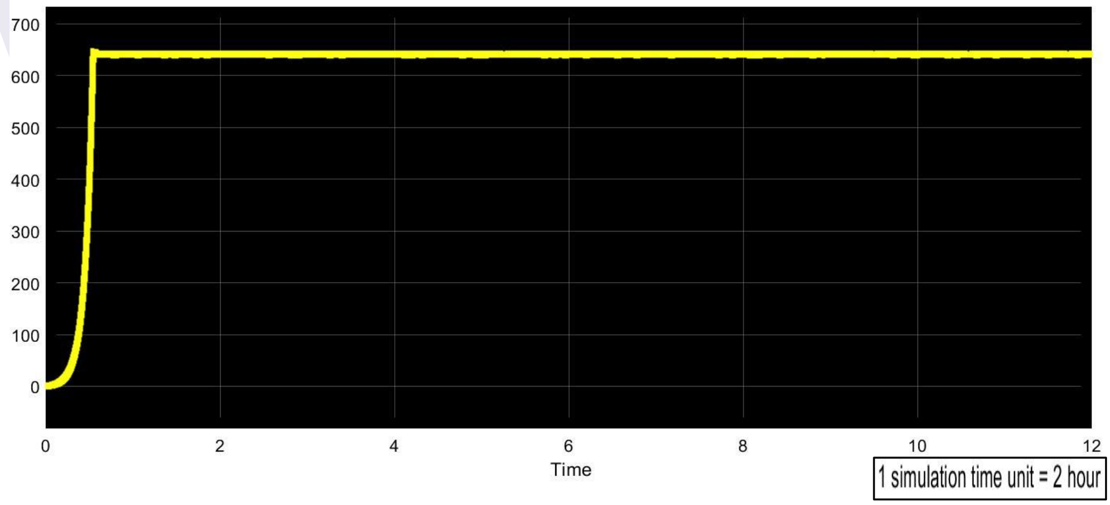



Figure 4.25: DC voltage of PMSG

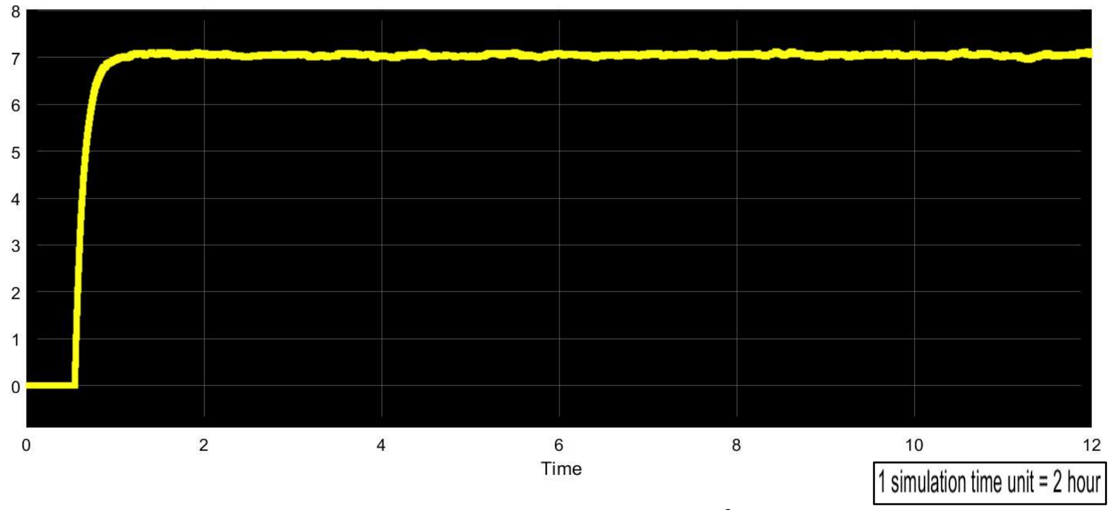



Figure 4.26: DC current of PMSG

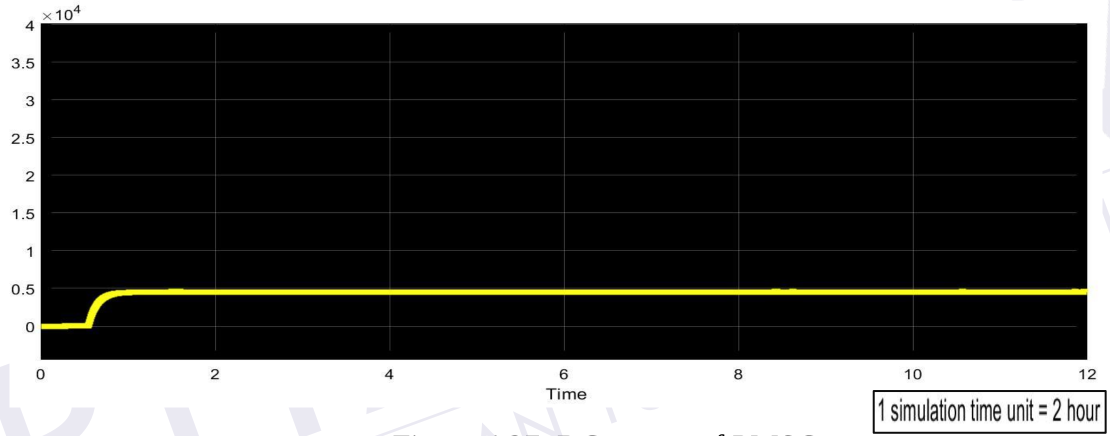



Figure 4.27: DC power of PMSG

As in the PV system the wind didn't reach the demand power, As a result the battery feeding the load during the day. So, state of charge continuous decrease. As demonstrate in Figure 4.28, 4.29 and 4.30 which is show state of charge, power and current of battery respectively. The figures demonstrate the common problem of the single source renewable energy source that's the renewable source unexpected as result it's wrong to depend on one source. Based on the figure, The wind system that feeding maximum power 14kw didn't reach the demand power as results the battery as shown in figure continuous decrease and the battery feeding the load during all the day.

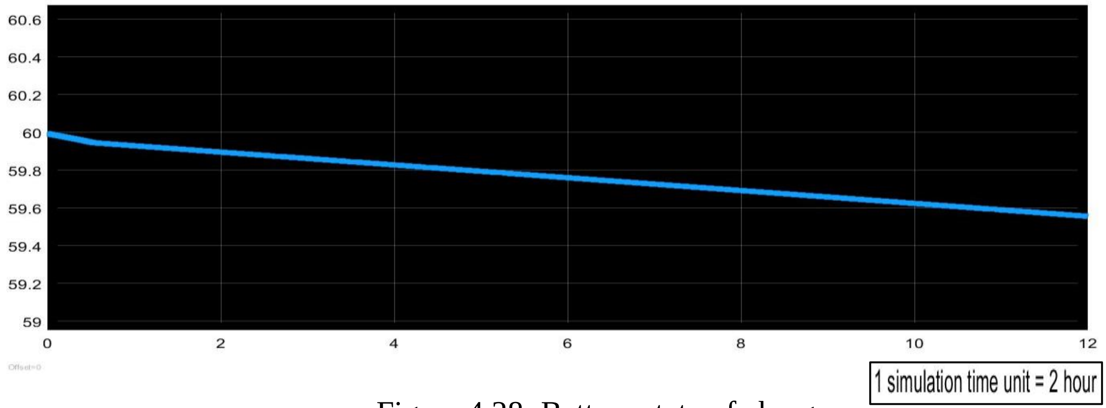



Figure 4.28: Battery state of charge

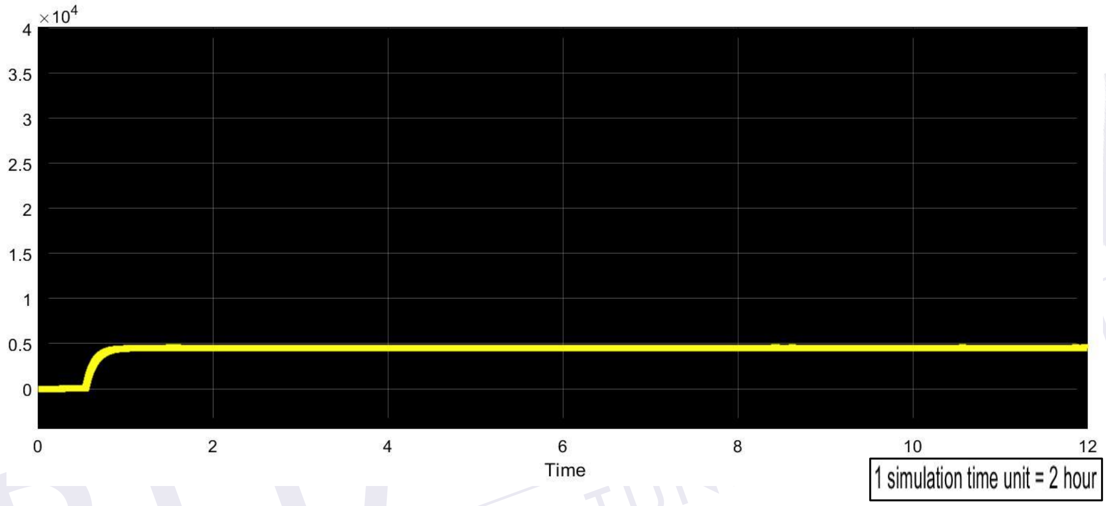



Figure 4.29: Power of battery

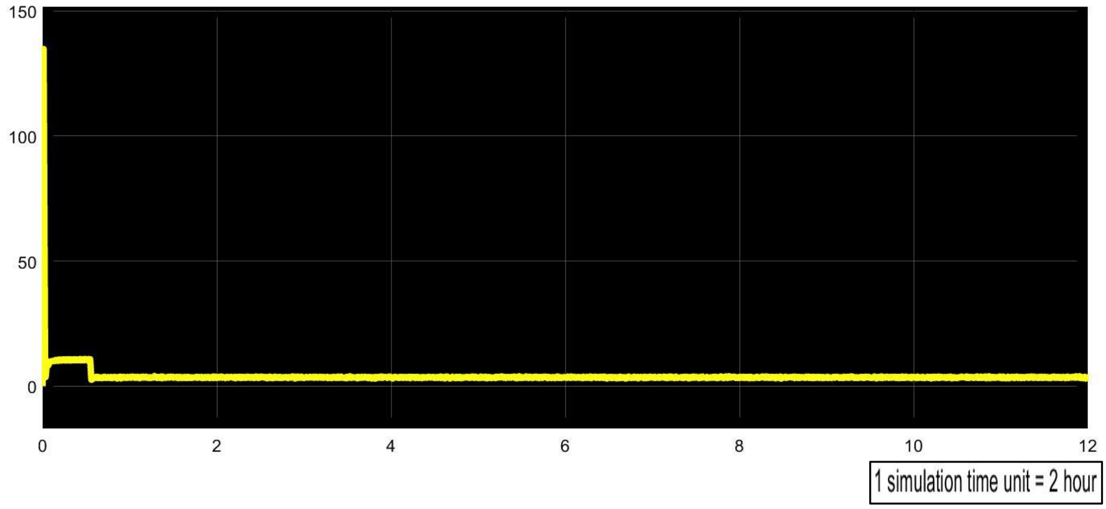



Figure 4.30: Current of battery

The battery as mention in PV system that's operate in 320V so it can charge and discharge depending on the direction of the bidirectional DC/DC converter which have controlled by using PI control technique battery voltage and output of

PI controller. The Figure 4.31, 4.32 and 4.33 shows voltage, current of battery and PI controller output. The Figure 4.33 shows clearly that the power generated by wind does not satisfied the demand load. The figure show that controller give trigged to the bidirectional DC/DC converter to operate as boost converter which is mean that battery fed with the wind the load.

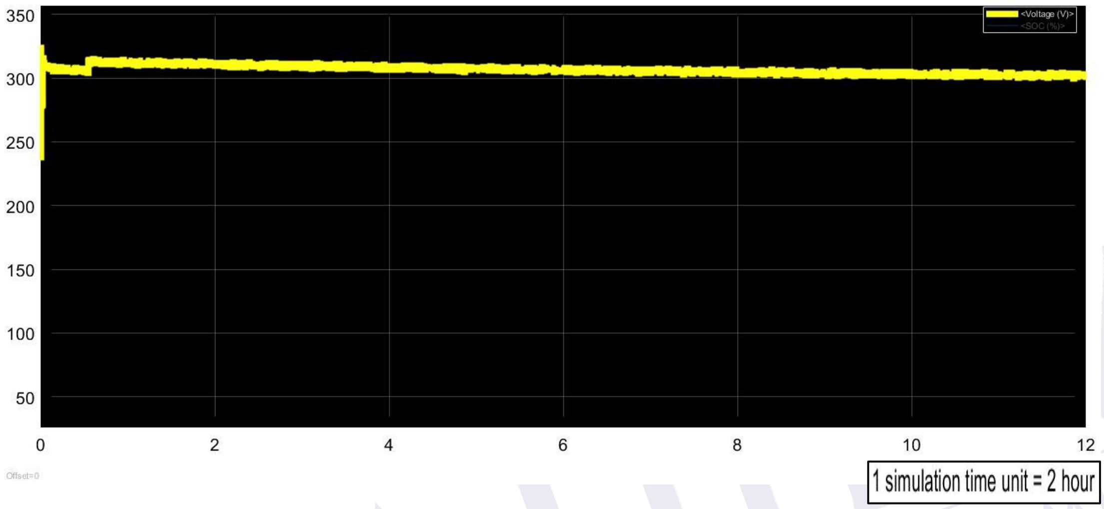



Figure 4.31: Voltage of battery

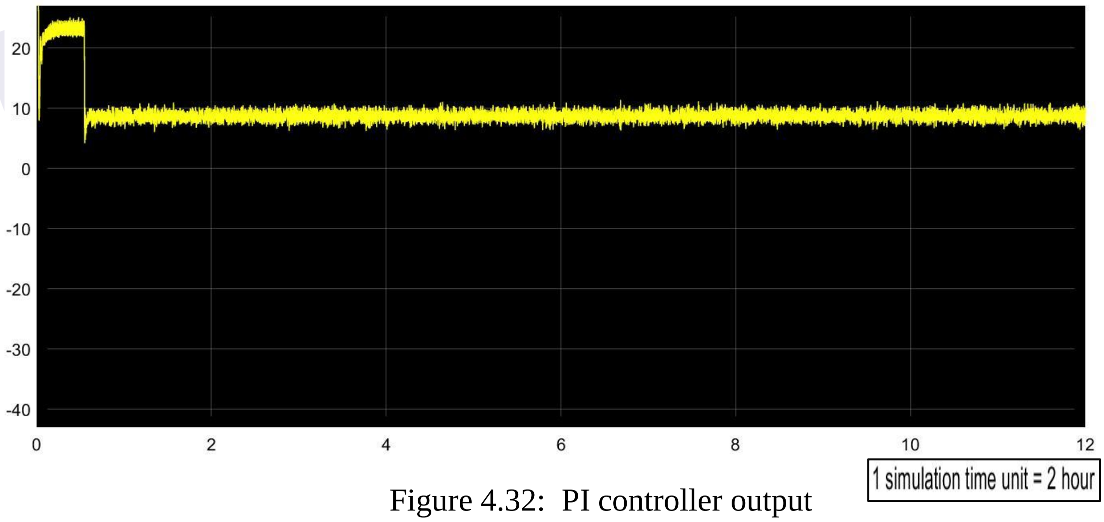



Figure 4.32: PI controller output

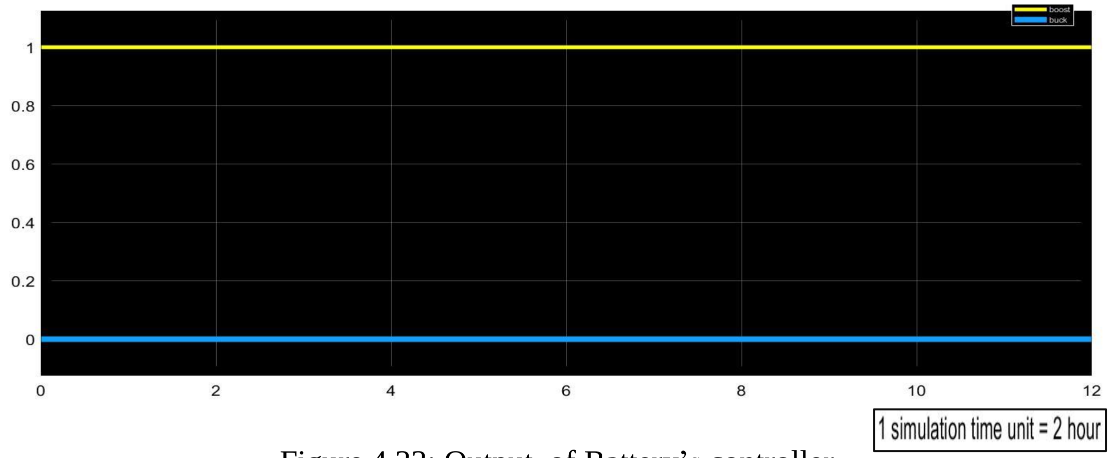



Figure 4.33: Output of Battery's controller

The Figures 4.34, 4.35 and 4.36 show the wind system DC voltage, current and power respectively. The figures show that the load faded with demand load consciously without distribution. As shown in the figures that the voltage of the DC 640 V which is the system DC voltage , 7.8 A and 5 KW

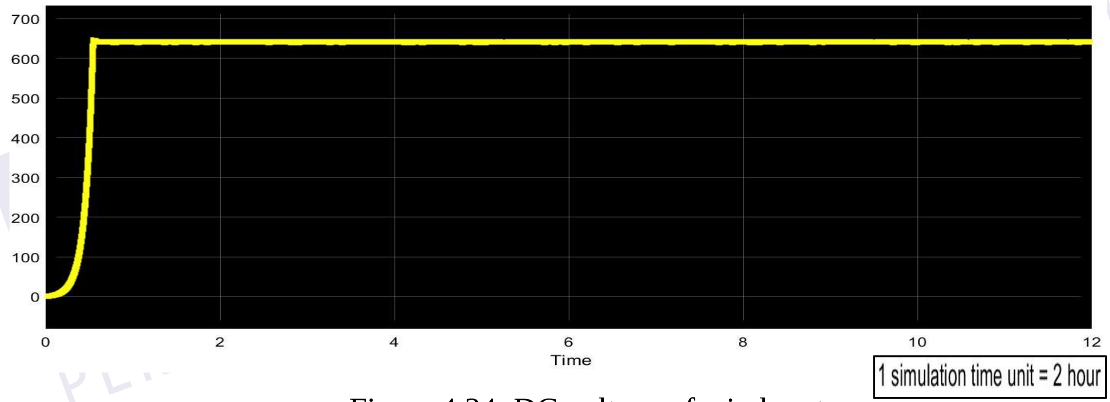



Figure 4.34: DC voltage of wind system

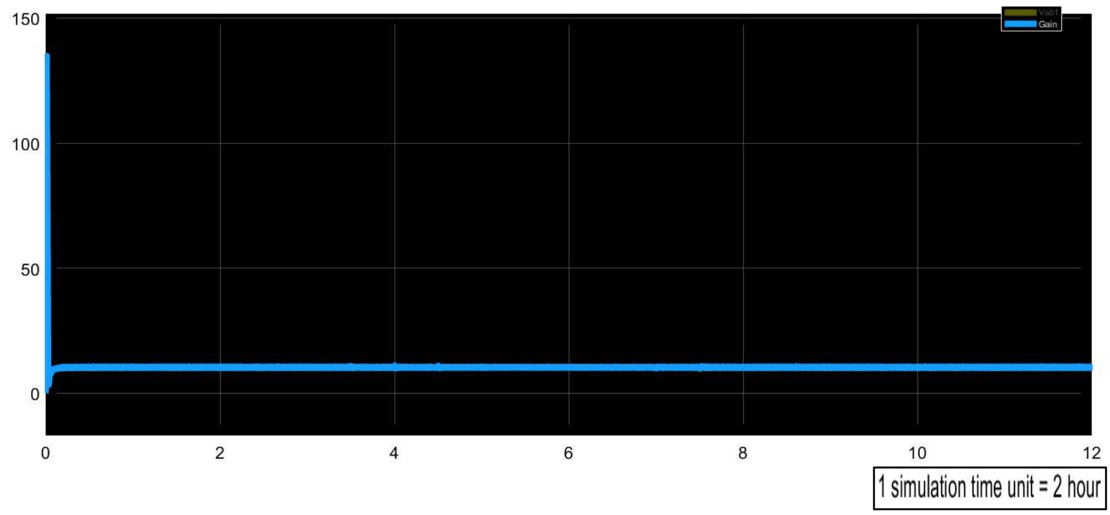



Figure 4.35: DC current of system

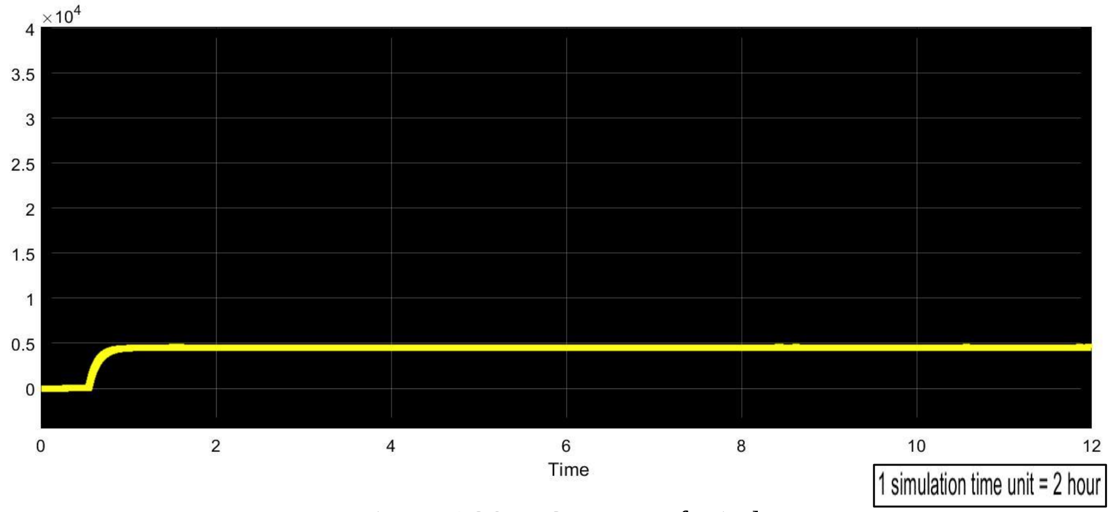



Figure 4.36: DC power of wind system

The last step to fed power into the load is inverting the power to AC voltage. The Figures 4.37 and 4.38 show the AC power parameters and presents the line to line voltage and AC rms voltage respectively, under Iraq system condition which is 680 V and 220 V respectively. The figure show that AC voltage line to line is pure since wave without distribution and the system work well to fed for householders. Moreover Load voltage and current shown in Figures 4.39 and 4.40 respectively. The load voltage and current are sin wave and no harmonics and very little distribution in voltage and current which is mean that wind system is stable. The distribution loads voltages and current is one of renewable drawback which is need to develop.



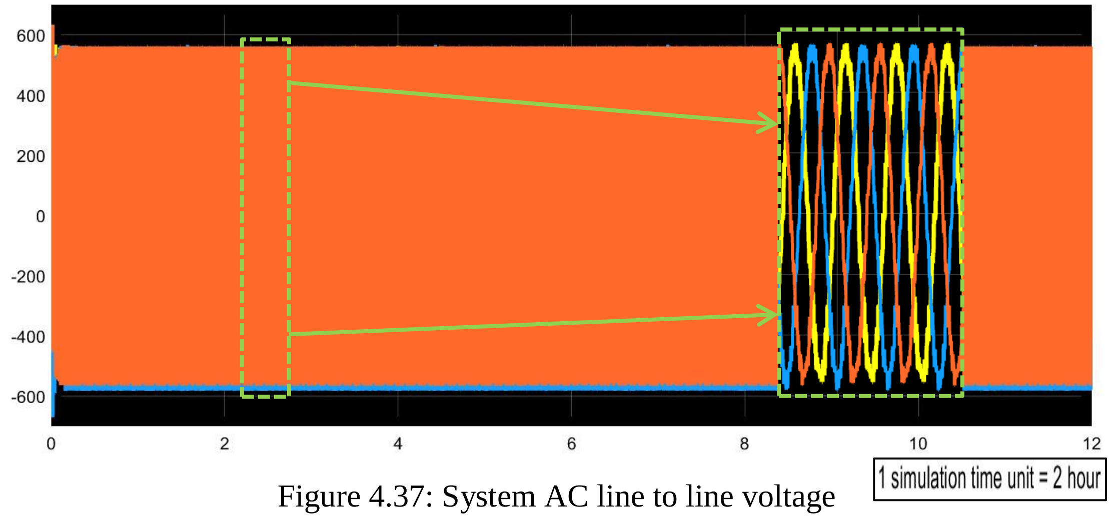



Figure 4.37: System AC line to line voltage

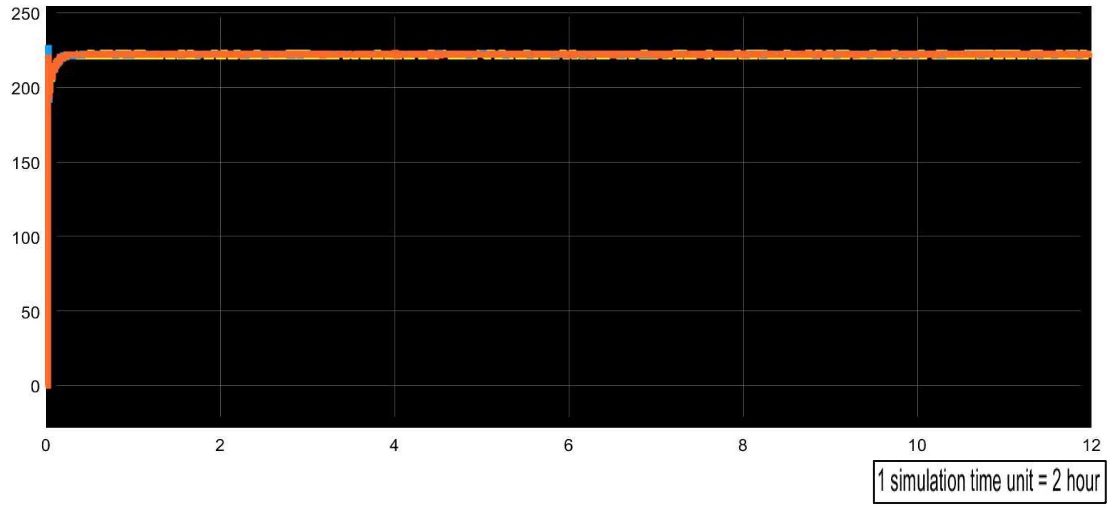



Figure 4.38: System AC RMS phase voltage

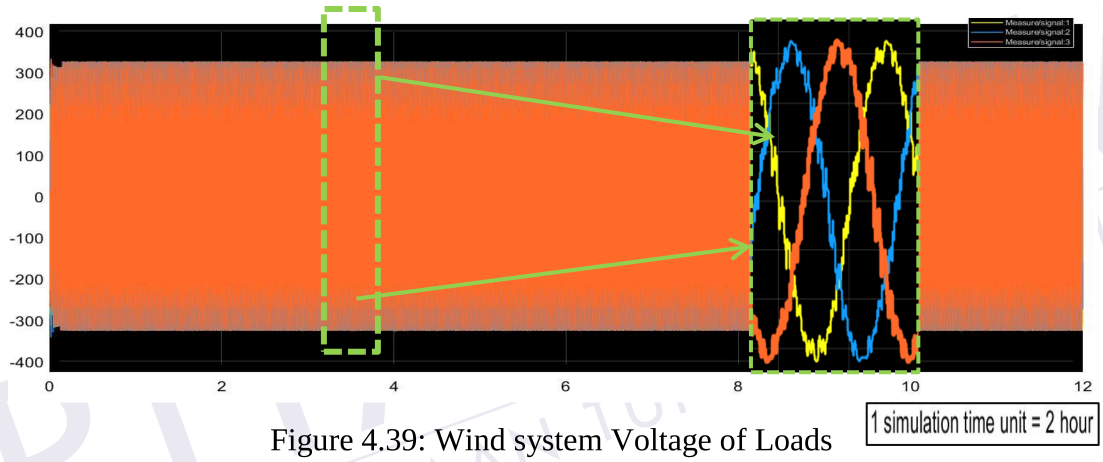



Figure 4.39: Wind system Voltage of Loads

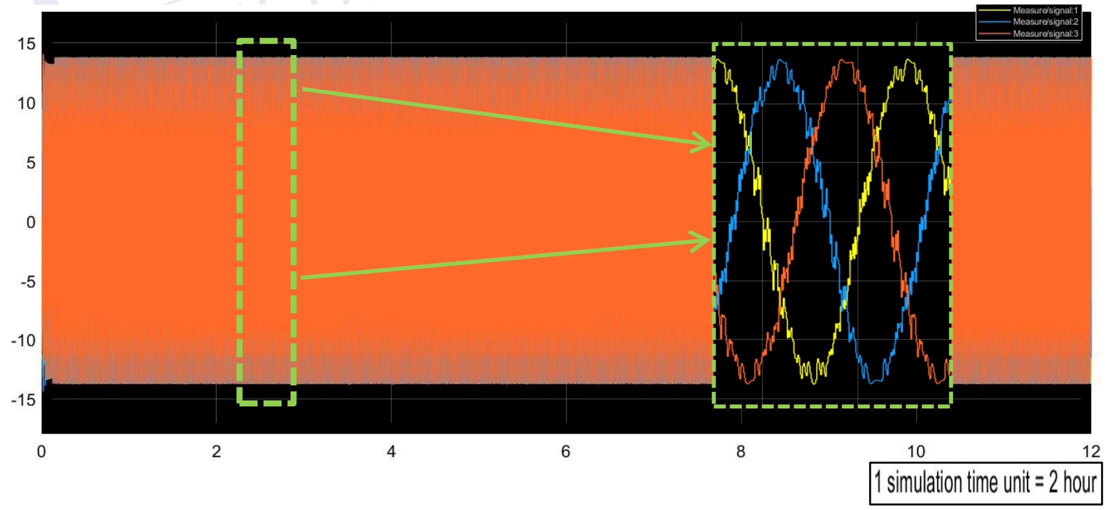
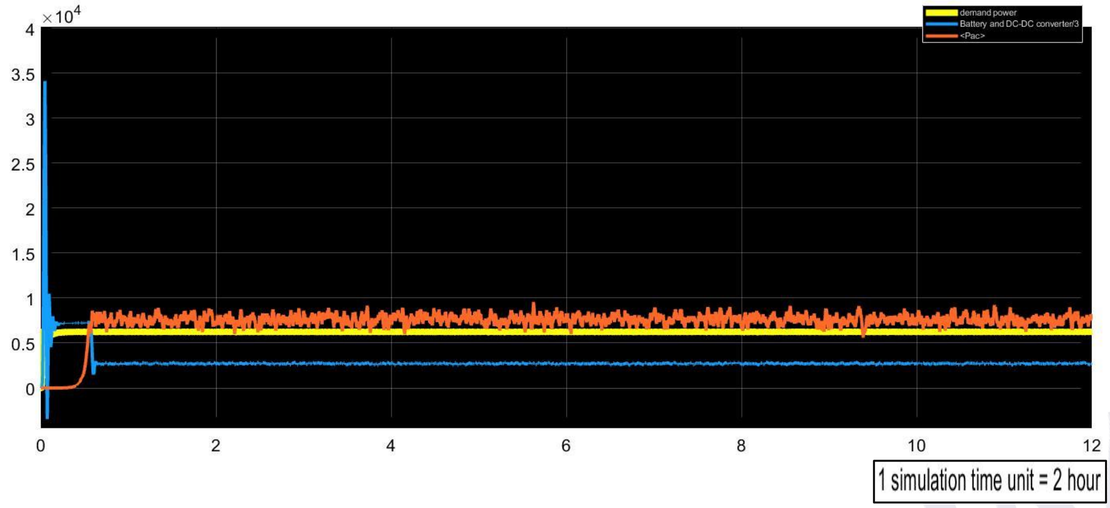



Figure 4.40: Wind system Current Loads

The overall system output, powers of wind system, battery and load demand power shown in Figure 4.41. As shown in the figure the powers of wind system and battery. It can be noticed the wind doesn't generated enough power to feed the demand power and battery fed part of demand power during all the day.




Figures 4.41: The overall wind system powers

## 4.5 Hybrid PV wind renewable energy power system

The purpose of the hybridization process that's the system doesn't depend on one renewable energy source and increase the generated power. The hybrid PV system has explained in section 3.5 in chapter III and the simulation shown in Figure 3.36. The Figure 4.42 showed overall system powers (PV, PMSG, battery and demand load) which demonstrated the purpose of the process. As shown in the figure When the sun is absent  during all the day expect in the middle of the day therefore solar radiation is also absent. PMSG with battery reach the demand power then in the middle of the day when the sun rise the PV generate power due sun rise which mean sun radiation used to charge the battery as  aresult the state of charge keep constant in the end of the day or decrease in very low amount as shown in Figure 4.43.

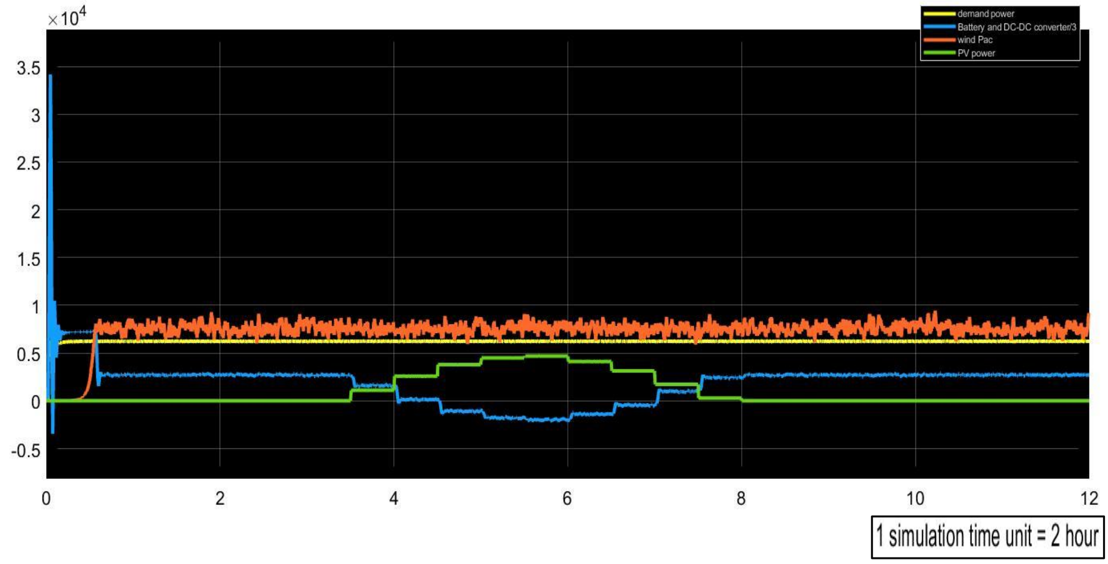



Figure 4.42: Overall hybrid system powers

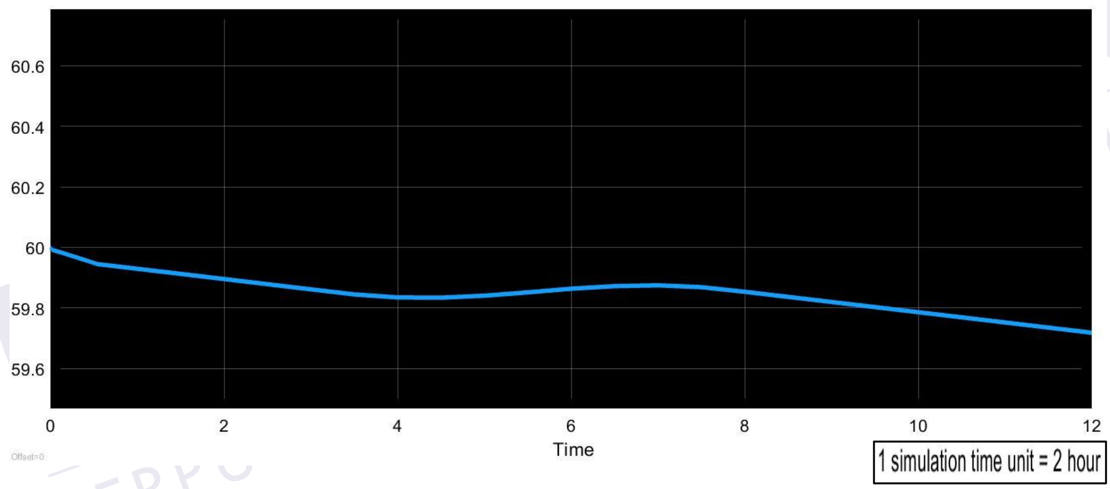



Figure 4.43: Battery state of charge

The output of the PI controller which consider as the main responsible for the battery charge/discharge the output of PI controller shown in Figure 4.44. The figure shows that in the middle of day, the output decrease to below zero because as explained that in the middle of day PV generated power to be the power generated by the PV plus the wind more than the demand power. Therefore the battery have some time to charge. The Figures 4.45, 4.46 and 4.47 demonstrated the battery charge and discharge clearly which is show the battery controller output, battery power and battery current respectively. The Figure 4.45 show the battery controller output which show that the DC/DC converter operate for some hours in the middle of the day as buck converter. Which is mean, the battery charge. Moreover the

Figures 4.46 and 4.47 shows the battery's power and current. We can notice that for some hours in the middle of the day they increase for negative which ensure that the battery have some hours to charge.

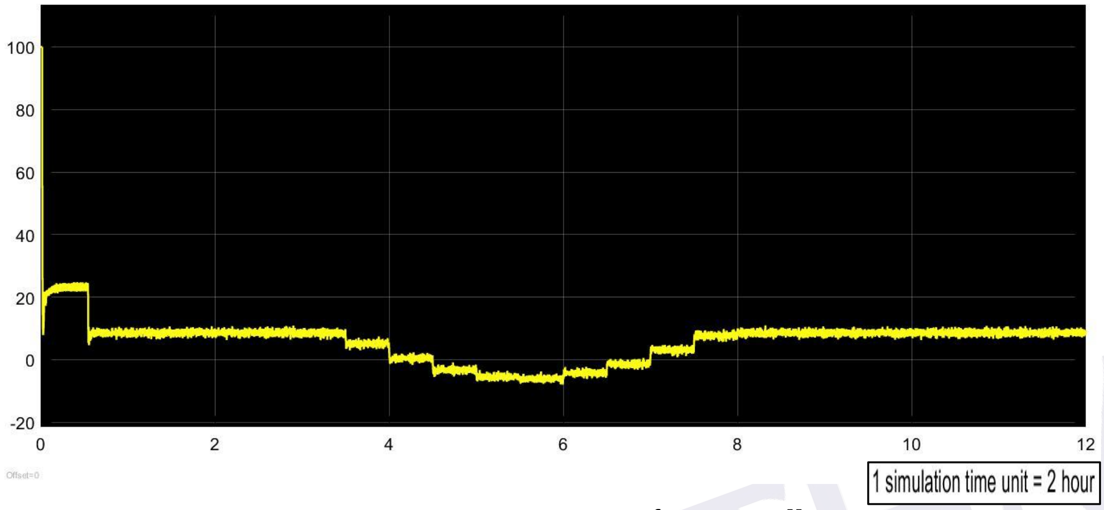



Figure 4.44: Output of PI controller

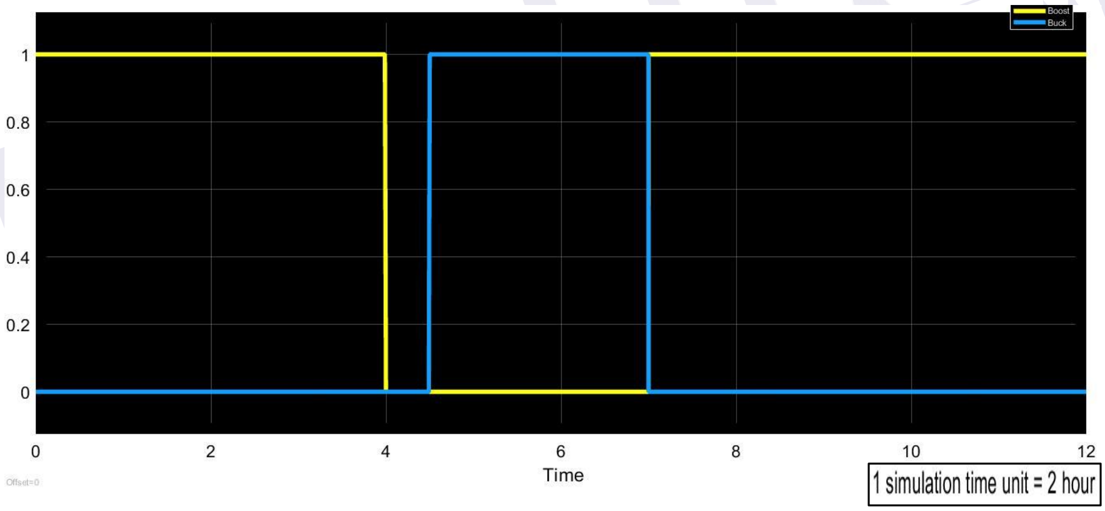



Figure 4.45: Battery controller output

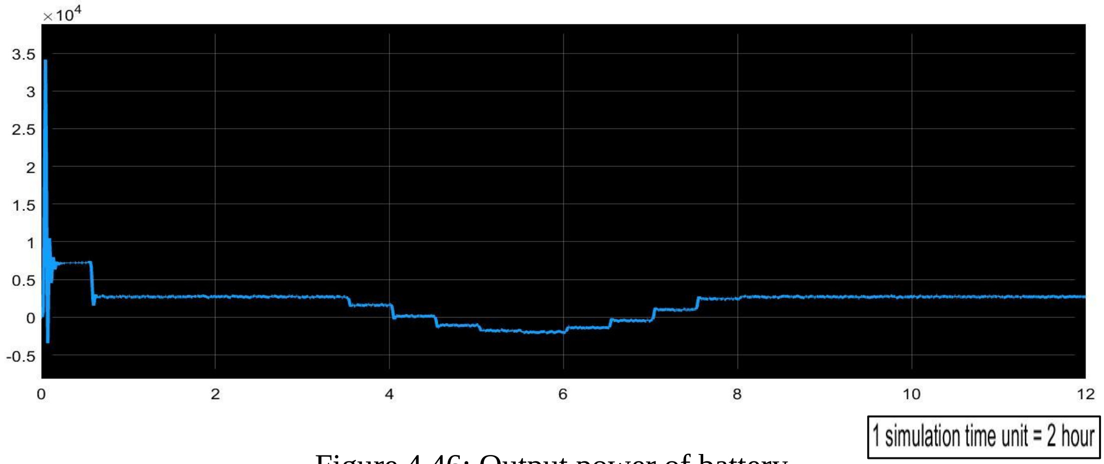



Figure 4.46: Output power of battery

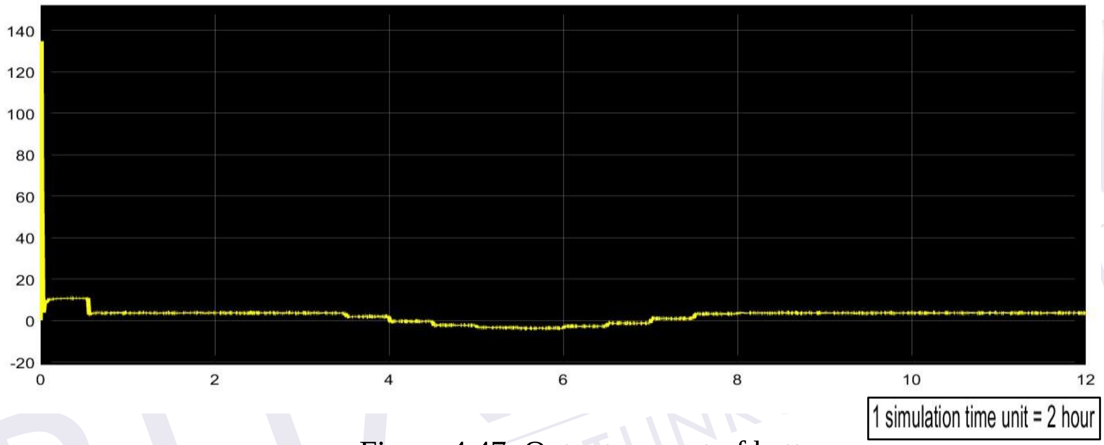



Figure 4.47: Output current of battery

The Figures 4.48 and 4.49 show the hybrid system DC voltage and current respectively. The figures show that the load faded with demand load consciously without distribution. As shown in the figures that the voltage of the DC 640 V which is the system DC voltage and 7.8 A

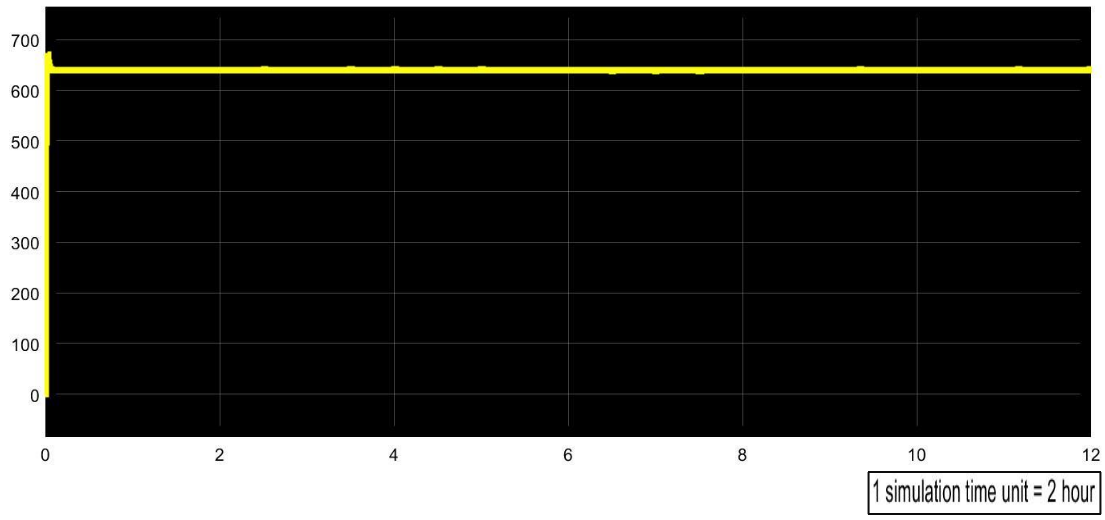



Figure 4.48: DC voltage of hybrid  system

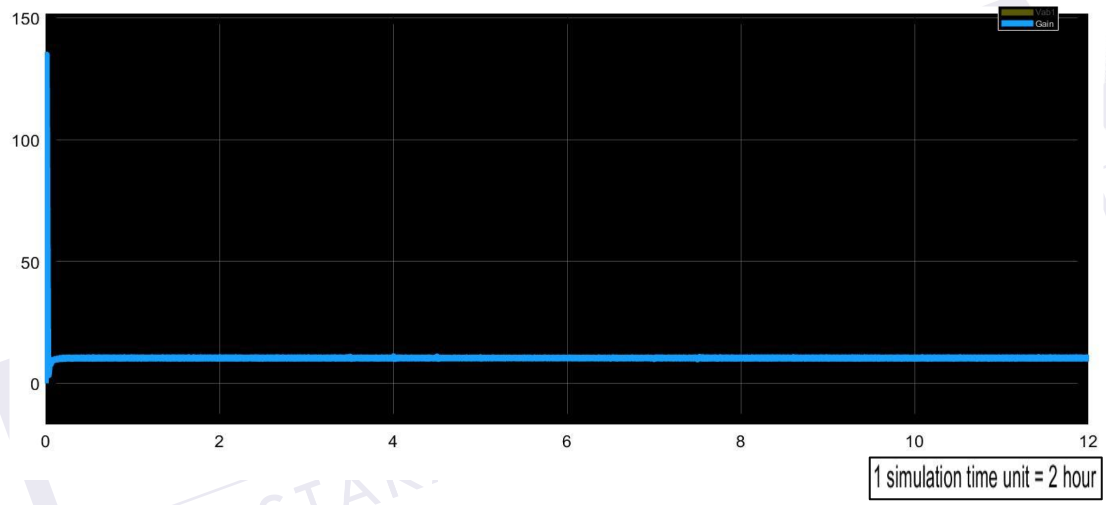



Figure 4.49: DC current of hybrid system

The last step to fed power into the load is inverting the power to AC voltage. The Figures 4.50 and 4.51 show the AC power parameters  and presents the line to line voltage and AC rms voltage respectively,  under Iraq system condition which is 680 V and 220 V respectively.  The figure show that AC voltage line to line is pure since wave without distribution and the system work well to fed for householders. Moreover Load voltage and current shown in Figures 4.52 and 4.53 respectively. The load voltage and current are sin wave and no harmonics and very little distribution in voltage and current which is mean that wind  system is stable. The distribution loads voltages and current is one of renewable drawback which is need to develop.

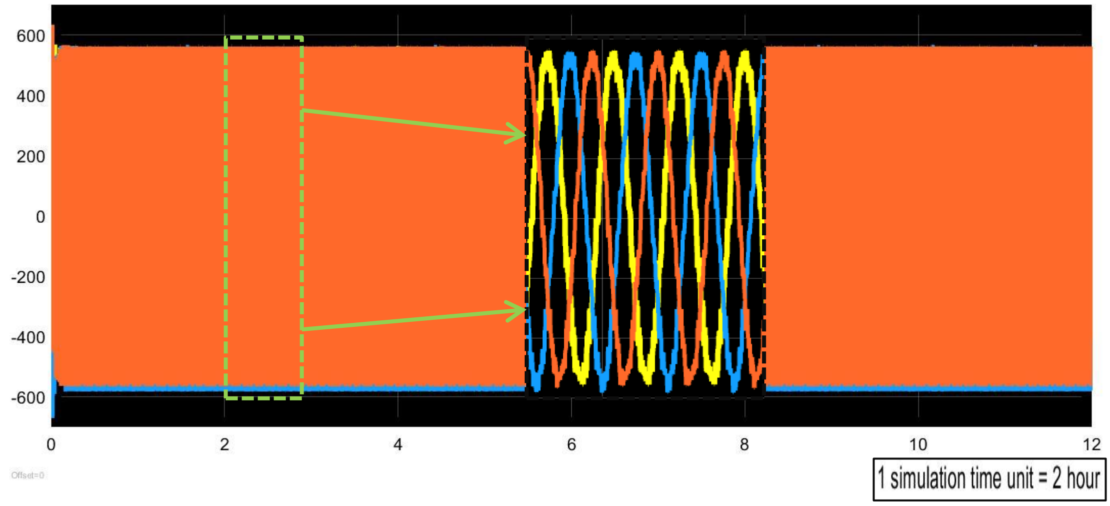



Figure 4.50: System AC line to line voltage

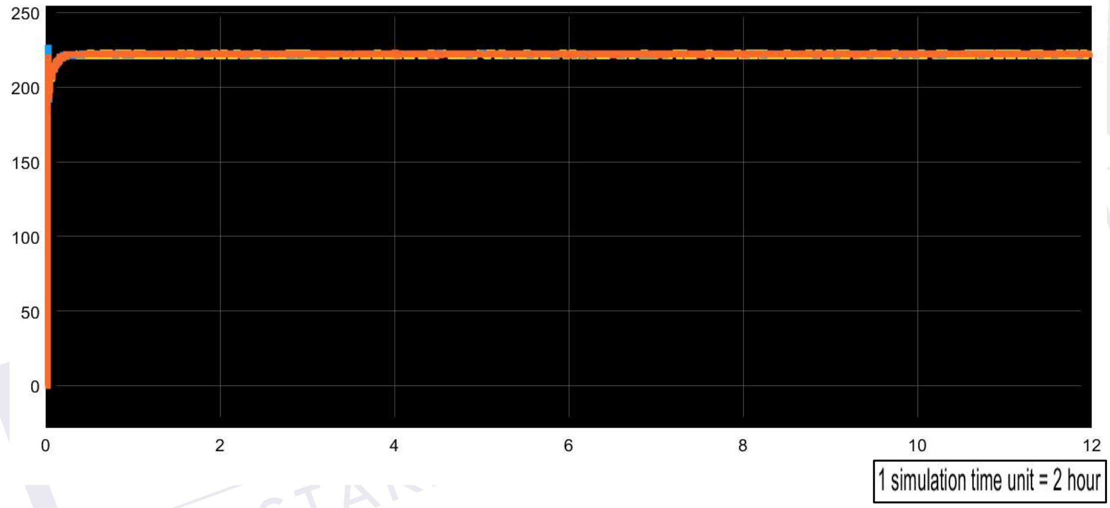



Figure 4.51: System AC RMS voltage

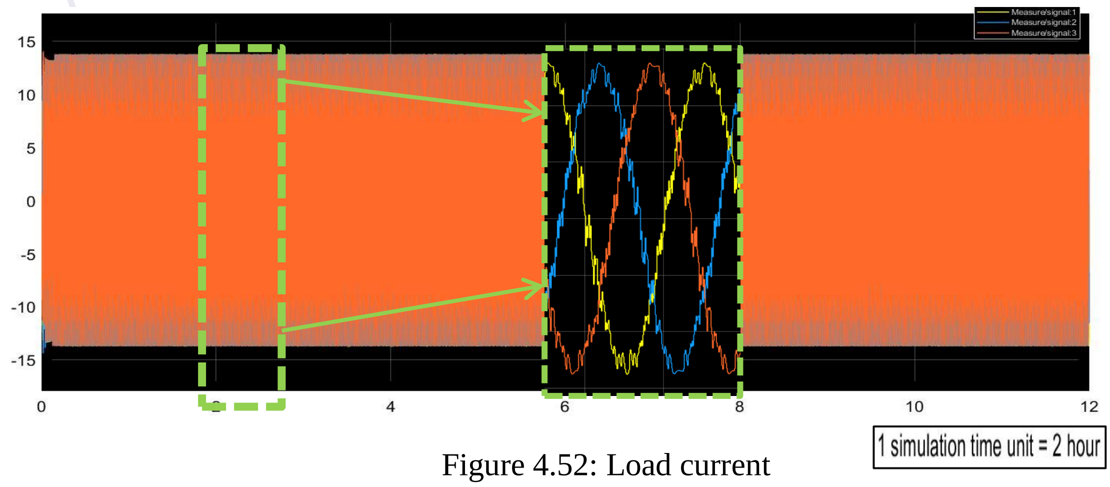



Figure 4.52: Load current

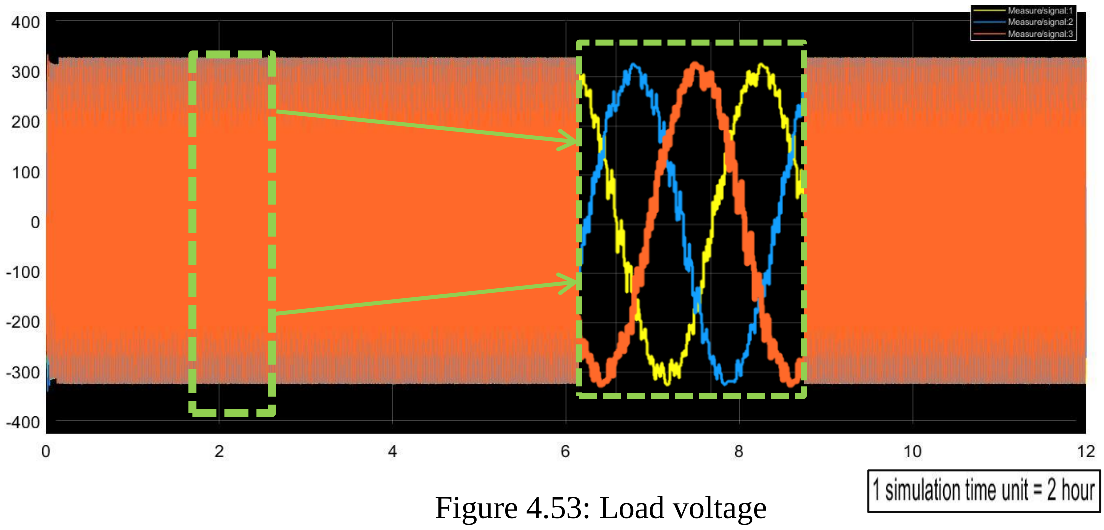



Figure 4.53: Load voltage

## 4.6 Conclusion

The summary of renewable systems shown in Table 4.2. wind System is better than PV due to the fact that is the wind system operates all day and don't have daily off interval like thus in PV. Moreover, the wind system affected less than in PV in the change of input so the wind is easy voltage control. But the wind is not different from the renewable source which is unexpected and has intermittent nature. The results show that the hybrid renewable system especially PV-wind system is excellent for rural electrification which is used the renewable sources as the main source for producing of the electricity. The hybrid system uses two renewable sources simultaneously so it isn't the depended on one source therefor the change of one source doesn't affect the hybrid system. The results show that under worst case the hybrid system supplied the demand power and the battery charged for a while. Therefore, at the end of the day, the state of charge decreases in little amount or keep it constant.

Table 4.2: The summary of renewable systems' results

| | PV system | Wind system | Hybrid system |
|---|---|---|---|
| DC voltage | 640 V | 640 V | 640 V |
| DC current (maximum) without battery | 7.3 A | 7.119 A | 14.4 A |
| DC Power (maximum) without battery | 4700 W/h | 4601.4 W/h | 9301.6 W/h |
| AC rms phase voltage with battery | 220 V | 220 V | 220 V |
| AC peak current with battery | 13 A | 13 A | 13 A |
| AC power with battery | 6250 W/h | 6250 W/h | 6250 W/h |

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

Chapter one recover background on renewable energy and the world demand for the renewable energy. It also contains the problem of the renewable sources that's unexpected and not stable and continuous with suggested solve to this problem by hybrid power system.

Chapter two review difference technique to improve the hybrid system. Nevertheless it's cover background or theory of the hybrid PV wind system modules.

Chapter three contain the modeling and implementation of the Simulink of PV renewable energy power system , wind renewable power system and hybrid PV-Wind renewable power system by using Matlab software.

Chapter four contain the results and analyze for the implementation that have been explain in chapter three.

As conclusion we can obtain that hybrid is better than the individual renewable system due to its overcome of the unexpected and intermittent nature of renewable sources. The hybrid PV-Wind is very suitable for electrification of rural areas due that areas that very difficult and pretty high cost to connect them to national grid.

## 5.2 Future Work

Base on the study, work and experience the future working focusing on the control and improve the using of artificial intelligence in the control. Moreover the Inverter and power quality of the renewable need to improve it and increase the research paper about this subject due to the fact that is till this point doesn't meet the demand and the power quality that faded to the householders is not excellent and need to be improve.

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